Journal of Sports Sciences

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rjsp20

Physical loading in professional soccer players: Implications for contemporary guidelines to encompass carbohydrate periodization

Liam Anderson, Barry Drust, Graeme L. Close & James P. Morton

To cite this article: Liam Anderson, Barry Drust, Graeme L. Close & James P. Morton (2022) Physical loading in professional soccer players: Implications for contemporary guidelines to encompass carbohydrate periodization, Journal of Sports Sciences, 40:9, 1000-1019, DOI: 10.1080/02640414.2022.2044135

To link to this article: https://doi.org/10.1080/02640414.2022.2044135

Published online: 06 Mar 2022.

JOURNAL OF SPORTS SCIENCES
2022, VOL. 40, NO. 9, 999–1018
https://doi.org/10.1080/02640414.2022.2044135

PHYSIOLOGY AND NUTRITION

OPEN ACCESS Check for updates

Physical loading in professional soccer players: Implications for contemporary guidelines to encompass carbohydrate periodization

Liam Anderson [a], Barry Drust [a], Graeme L. Close [b] and James P. Morton [b]

[a]School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham, UK; [b]Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Tom Reilly Building, Byrom St Campus, Liverpool John Moores University, Liverpool, L3 6AF, UK

ABSTRACT

Despite more than four decades of research examining the physical demands of match-play, quantification of the customary training loads of adult male professional soccer players is comparatively recent. The training loads experienced by players during weekly micro-cycles are influenced by phase of season, player position, frequency of games, player starting status, player-specific training goals and club coaching philosophy. From a macronutrient perspective, the periodization of physical loading within (i.e., match versus training days) and between contrasting micro-cycles (e.g., 1, 2 or 3 games per week schedules) has implications for daily carbohydrate (CHO) requirements. Indeed, aside from the well-recognised role of muscle glycogen as the predominant energy source during match-play, it is now recognised that the glycogen granule may exert regulatory roles in activating or attenuating the molecular machinery that modulate skeletal muscle adaptations to training. With this in mind, the concept of CHO periodization is gaining in popularity, whereby CHO intake is adjusted day-by-day and meal-by-meal according to the fuelling demands and specific goals of the upcoming session. On this basis, the present paper provides a contemporary overview and theoretical framework for which to periodize CHO availability for the professional soccer player according to the "fuel for the work" paradigm.

ARTICLE HISTORY
Accepted 11 February 2022

KEYWORDS
Glycogen; training adaptation; football; soccer; skeletal muscle

1. Introduction

An annual macrocycle for professional soccer players is typically categorised into three distinct phases of pre-season (6 weeks), in-season (39 weeks) and off-season (7 weeks) (Reilly, 2007). Throughout the in-season period, players may compete in 40–60 matches that could encompass domestic, continental and global competitions. In addition, players also complete ~180 training sessions (Anderson et al., 2016) with the volume and intensity of such session's dependent on the proximity to the next game (Anderson et al., 2015); see (Figure 1). For example, during a two or three game per week microcycle, players are exposed to a higher weekly accumulative load (e.g., total distance covered, and distances covered within high-intensity speed zones) that is largely reflective of increased loading associated with match play, as opposed to high training loads. Such scenarios present the challenge to ensure optimal match-day performance and recovery (Morgans et al., 2014a; Nédélec et al., 2014) whilst also preventing injury (Dellal et al., 2013; Dupont et al., 2010) and symptoms of over-training (Morgans et al., 2014a). In the traditional one game per week microcycle, however, players are usually exposed to a higher physical loading from training given the extended recovery time available between consecutive games. In such situations, the daily training load may be periodized according to the club's coaching philosophy (Akenhead et al., 2016; Anderson et al., 2015; Malone et al., 2015; Martin-Garcia et al., 2018; Oliveira et al., 2020; Stevens et al., 2017), though the days with the highest training load tend to be three or four days before the next game (Akenhead et al., 2016; Anderson et al., 2015; Martin-Garcia et al., 2018; Oliveira et al., 2020; Stevens et al., 2017); see (Figure 1 and Table 1).

From a nutritional perspective, the role of muscle glycogen as the main energy source for soccer match play was first documented in the early 1970s (Saltin, 1973). On this basis, nutritional guidelines for soccer players typically advised a high daily carbohydrate (CHO) intake, with previous recommendations of 5–7 $g.kg^{-1}$ body mass on training days and 7–12 $g.kg^{-1}$ on those days requiring enhanced daily recovery and match preparation (Burke et al., 2006). Nonetheless, with our increasing understanding of the energy requirements and periodization of physical loading patterns completed by elite players (i.e., as dependent on fixture schedule), it is perhaps relevant to also consider a more nuanced approach to CHO recommendations that takes into account both meal-by-meal and day-by-day CHO requirements. Indeed, although the concept of CHO periodization has obvious relevance to the promotion of match day performance (Bangsbo et al., 1992) and recovery (Gunnarsson et al., 2013; Krustrup et al., 2006), there is a growing body of literature suggesting that carefully implemented models of within and between day CHO periodization may enhance skeletal muscle adaptations to aerobic (Impey et al., 2018) and high-intensity interval-type training (Morton et al., 2009). In addition to its well documented role as an energy substrate, our understanding of the glycogen granule has since

CONTACT James P. Morton j.p.morton@ljmu.ac.uk Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Tom Reilly Building, Byrom St Campus, Liverpool John Moores University, L3 6AF, UK

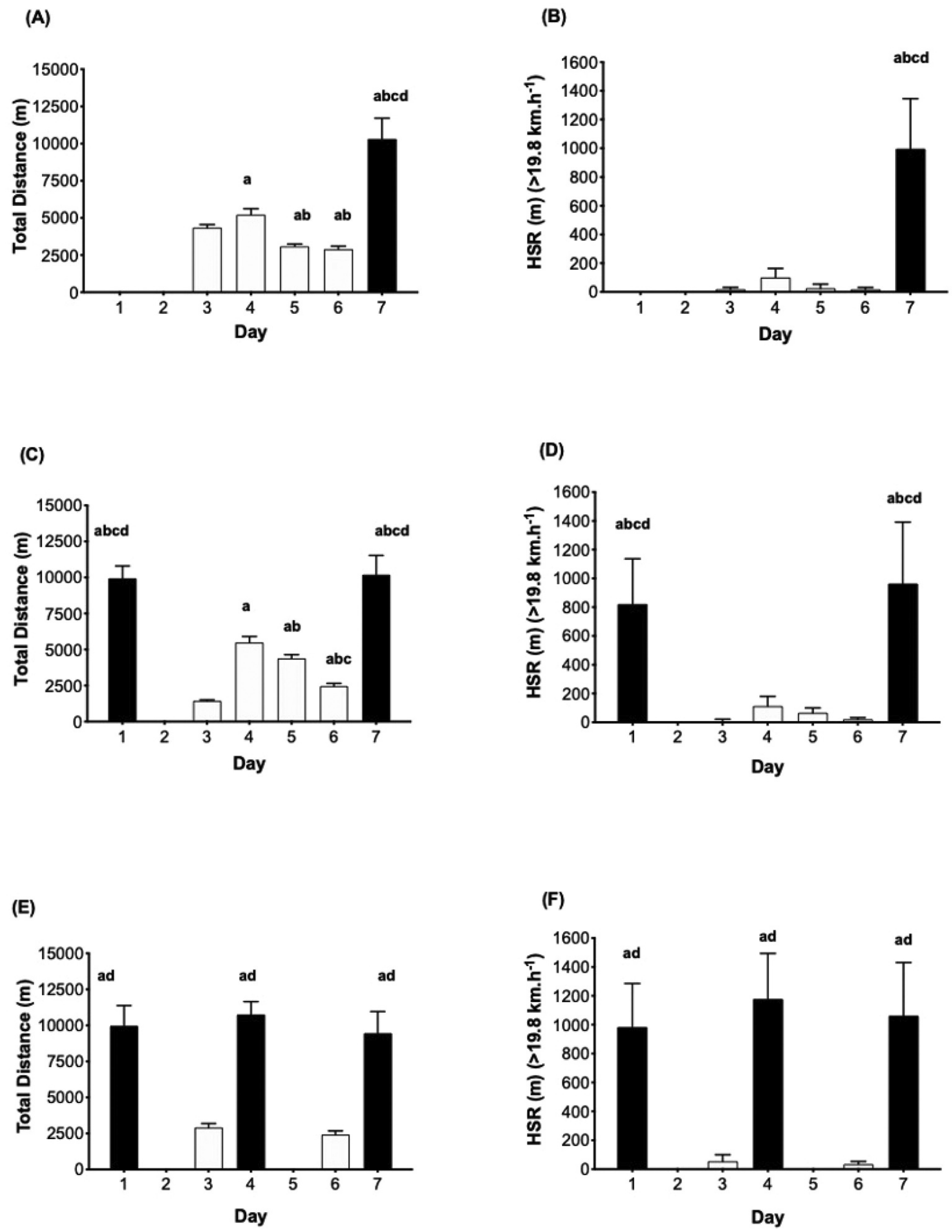

Figure 1. Total distance and high-speed running completed in training sessions and matches by professional players from the EPL. Figures A and B = one-game week, Figures C and D = two-game week and Figures E and F = three-game week. White bars = training days and black bars = match days. a denotes difference from day 3, b denotes difference from day 4, c denotes difference from day 5 and d denotes difference from day 6, all $P < 0.05$. HSR = High Speed Running. Data redrawn from Anderson et al. (2015).

expanded to that of a regulator of training adaptations (Philp et al., 2012; Bartlett et al., 2015; Hawley & Morton, 2014). Such recognition is based on the repeated observations that commencing and/or recovering from exercise with "low" muscle glycogen potentiates the activation of cell signalling pathways that regulate oxidative adaptations of human skeletal muscle (see Figure 2). From a practical perspective, this so-called "train-low" paradigm has been translated as "fuelling for the work required" whereby daily CHO intake is adjusted day-by-day and meal-by-meal according to the upcoming activity and the desired outcome of the exercise session i.e., promoting exercise intensity versus stimulating metabolic adaptations (Impey et al., 2018). Although such models of nutritional periodization are gaining increased recognition amongst endurance sports (Burke et al., 2018; Impey et al., 2018; Stellingwerff et al., 2019), no such models have yet been developed for the professional soccer player.

With this in mind, the aim of the present review is to provide a theoretical and contemporary overview of CHO requirements for adult male players for both training and match play that takes into account the periodization of physical loading within and between contrasting microcycles. We also provide commentary of potential CHO recommendations for players performing concurrent training as well as those with unique positional and training demands (i.e., goalkeepers). Our aim is to provide a practical framework that may assist practitioners in formulating daily CHO intakes which are deemed sufficient according to the typical loading patterns experienced by

Table 1. An overview of previously published in-season physical training load expressed with commonly reported GPS metrics.

Reference	Subjects	Notes	System Used	Position/Type of Session/Phase of the Season	Duration (mins)	Total Distance (m)	Meters Per minute (m/min)	Running Distance (m)	High Speed Running (m)	Sprinting (m)	Accels	Decels
Gaudino et al. (2013)	26 English Premier League Players	Average in season data with the warmup not included	GPS 15 Hz				Speed Zones=	14.4–19.8 km.hr^{-1}	19.8–25.2 km.hr^{-1}	>25.2 km. hr^{-1}		
				CD	54 ± 18	3498 ± 1204	-	285 ± 128	72 ± 57	16 ± 31	-	-
				WD	56 ± 18	3647 ± 1302	-	370 ± 218	112 ± 89	20 ± 33	-	-
				CM	58 ± 20	4133 ± 1538	-	442 ± 332	108 ± 105	21 ± 37	-	-
				WM	55 ± 17	3618 ± 1138	-	347 ± 183	91 ± 77	17 ± 28	-	-
				ATT	60 ± 17	3906 ± 1183	-	344 ± 180	116 ± 112	21 ± 38	-	-
Owen et al. (2014)	10 Scottish Premier League Players	Average training data from both high intensity and low intensity training sessions	GPS 5 Hz				Speed Zones =		>21.6 km. hr			
				HI 1	-	6872 ± 592	83.2 ± 2.9	-	442 ± 164	-	-	-
				HI 2	-	11,860 ± 1574	92.3 ± 10.2	-	514 ± 359	-	-	-
				HI 3	-	4817 ± 268	78.0 ± 5.0	-	553 ± 109	-	-	-
				HI 4	-	9364 ± 562	92.9 ± 5.3	-	68 ± 44	-	-	-
				LI 1	-	2438 ± 273	40. 6 ± 4.5	-	0 ± 0	-	-	-
				LI 2	-	2647 ± 720	33.1 ± 9.0	-	26 ± 14	-	-	-
				LI 3	-	2222 ± 172	37.0 ± 2.8	-	0 ± 0	-	-	-
				LI 4	-	2311 ± 190	38.5 ± 3.1	-	0 ± 0	-	-	-
Gaudino et al. (2015)	22 English Premier League Players	Average in season data with the warmup not included	GPS 10 Hz				Speed Zones =	>14. km. hr^{-1}	>19.8 km. hr^{-1}		>3 m/s^2	>3 m/s^2
				38 week in season	57 ± 16	3545 ± 1038	63 ± 8	426 ± 218	109 ± 95	-	18 ± 10	25 ± 11
Malone et al. (2015)	30 English Premier League Players	3 in-season microcycles from different stages of the in season	GPS 15 Hz				Speed Zones =		>19.8 km. hr^{-1}			
				Week 7	75 ± 26	6182 ± 1841	81 ± 9	-	243 ± 229	-	-	-
				Week 24	72 ± 13	6105 ± 1121	85 ± 6	-	225 ± 213	-	-	-
				Week 39	61 ± 21	4714 ± 1581	79 ± 7	-	146 ± 104	-	-	-
Anderson et al. (2015)	12 English Premier League Outfield Players	Average for a 1 game week lead in	GPS 10 Hz				Speed Zones =	14.4–19.8 km.hr^{-1}	19.8–25.2 km.hr^{-1}	>25.2 km. hr^{-1}		
				MD-4	63 ± 0	4349 ± 204	69 ± 3	176 ± 37	18 ± 13	0 ± 0	-	-
				MD-3	65 ± 0	5223 ± 406	80 ± 6	472 ± 129	95 ± 57	6 ± 8	-	-
				MD-2	60 ± 0	3097 ± 149	52 ± 2	129 ± 58	26 ± 28	0 ± 1	-	-
				MD-1	70 ± 0	2912 ± 192	42 ± 3	101 ± 46	16 ± 11	2 ± 3	-	-
Akenhead et al. (2016)	33 English Premier League Outfield Players	Average over a season broken down into each specific microcycle day	GPS 10 Hz				Speed Zones =		>20.8 km. hr^{-1}	>24.1 km. hr^{-1}		
				MD-5	76 ± 16 (72–80)	4925 ± 1312 (4650–5200)	-	-	44 ± 160 (11–77)	7 ± 50(0–17)	-	-
				MD-4	87 ± 8 (83–91)	6234 ± 1368 (5966–6501)	-	-	190 ± 165 (158–222)	46 ± 51 (36–55)	-	-
				MD-2	81 ± 12 (77–85)	5287 ± 1363 (5017–5556)	-	-	141 ± 165 (109–175)	28 ± 51 (18–37)	-	-
				MD-1	60 ± 11 (56–64)	3493 ± 1324 (3221–3765	-	-	23 ± 162 (0–56)	6 ± 50(0–16)	-	-

(*Continued*)

Table 1. (Continued).

Reference	Subjects	Notes	System Used	Position/Type of Session/Phase of the Season	Duration (mins)	Total Distance (m)	Meters Per minute (m/min)	Running Distance (m)	High Speed Running (m)	Sprinting (m)	Accels	Decels
Stevens et al. (2017)	28 Dutch Eredivisie Outfield Players	Average over a season broken down into each specific microcycle day (Lead in from MD-4)	LPM 31 Hz (Inmotio)				Speed Zones =	14.4–19.8 km.hr^{-1}	>19.8 km.hr^{-1}		1.5–3 m/s^2 (>3 m/s^2)	1.5–3 m/s^2 (>3 m/s^2)
				MD-4	88 ± 11	7267 ± 913	-	834 ± 169	249 ± 85	-	131 ± 31 (66 ± 18)	98 ± 23 (49 ± 16)
				MD-3	82 ± 7	6120 ± 1188	-	692 ± 219	281 ± 134	-	82 ± 25 (44 ± 13)	64 ± 18 (30 ± 11)
				MD-2	77 ± 12	5219 ± 881	-	510 ± 156	175 ± 108	-	81 ± 21 (45 ± 15)	65 ± 17 (29 ± 11)
				MD-1	59 ± 7	3848 ± 454	-	328 ± 101	106 ± 53	-	55 ± 13 (26 ± 8)	44 ± 10 (23 ± 8)
Anderson et al., 2017a)	6 English Premier League Players	Average data for 2 MD+2/-1 training sessions	GPS 10 Hz				Speed Zones =	14.4–19.8 km.hr^{-1}	19.8–25.2 km.hr^{-1}	>25.2 km.hr^{-1}		
				MD+2/-1	52 ± 26 (63)	2865 ± 1494 (4258–2679)	45.9 ± 23.8 (68.0–44.1)	171 ± 122 (375–115)	27 ± 25 (70–4)	2 ± 4(10–0)	-	-
				MD+2/-1	46 ± 0 (46)	2187 ± 355 (2356–1680)	47.8 ± 7.8 (59.8–36.6)	91 ± 77 (225–3)	24 ± 35 (90–0)	5 ± 7 (14–0)	-	-
Owen et al. (2017)	16 Swiss Super League Players	Average daily lead in data for 6 weeks in season	GPS 10 Hz				Speed Zones =		21.6–25.2 km.hr^{-1}	>25.2 km.hr^{-1}		
				MD-4	-	5813	79.7	-	75	11	-	-
				MD-3	-	6644	72.9	-	114	40	-	-
				MD-2	-	5755	90.2	-	75	16	-	-
				MD-1	-	3338	64.1	-	93	1	-	-
Martin-Garcia et al. (2018)	24 Spanish La Liga Reserve Players	Average load for each lead in day over an entire in season	GPS 10 Hz				Speed Zones =		>19.8 km.hr^{-1}	>25.2 km.hr^{-1}	>3 m/s^2	>3 m/s^2
				MD+1 C	-	5226 ± 790	-	-	107 ± 104	26 ± 44	144 ± 54	137 ± 49
				MD+1 R	-	3827 ± 1069	-	-	125 ± 123	21 ± 37	66 ± 46	61 ± 44
				MD-4	-	5123 ± 905	-	-	246 ± 149	56 ± 60	128 ± 37	115 ± 33
				MD-3	-	5603 ± 1206	-	-	218 ± 119	34 ± 38	119 ± 44	108 ± 41
				MD-2	-	4221 ± 620	-	-	87 ± 74	12 ± 28	104 ± 37	99 ± 37
				MD-1	-	2675 ± 602	-	-	50 ± 57	8 ± 18	59 ± 22	57 ± 21
Clemente et al. (2019)	29 Players from both the Portuguese Second Division and Dutch Second Division	Average daily lead in data for 7 weeks in season	GPS 10 Hz				Speed Zones =	14–20 km.hr^{-1}	>20 km.hr^{-1}			
				MD+1	-	6023 ± 1691	84.0 ± 11.1	514 ± 229	156 ± 84	-	-	-
				MD+2	-	6277 ± 1422	87.8 ± 19.4	573 ± 371	138 ± 118	-	-	-
				MD-5	-	7063 ± 1460	106.2 ± 18.1	990 ± 360	391 ± 259	-	-	-
				MD-4	-	6077 ± 1054	80.7 ± 13.4	523 ± 182	177 ± 82	-	-	-
				MD-3	-	6919 ± 1846	83.1 ± 8.4	623 ± 269	247 ± 240	-	-	-
				MD-2	-	5701 ± 1272	73.2 ± 12.4	532 ± 279	246 ± 200	-	-	-
				MD-1	-	4585 ± 1053	65.9 ± 14.9	343 ± 172	143 ± 117	-	-	-

(Continued)

Table 1. (Continued).

Reference	Subjects	Notes	System Used	Position/Type of Session/Phase of the Season	Duration (mins)	Total Distance (m)	Meters Per minute (m/min)	Running Distance (m)	High Speed Running (m)	Sprinting (m)	Accels	Decels
Oliveira et al. (2019a)	19 Premier Liga Players (Champions League team)	Average training data from 10 mesocycles throughout the in season	GPS 10 Hz				Speed Zones =		>19 km.hr^{-1}			
				Mesocycle 1	81.6 ± 1.1	5589 ± 100	68.6 ± 1.1	-	227 ± 14	-	-	-
				Mesocycle 2	78.4 ± 1.6	5248 ± 156	66.8 ± 0.9	-	192 ± 17	-	-	-
				Mesocycle 3	77.4 ± 1.9	5691 ± 132	74.0 ± 1.7	-	182 ± 19	-	-	-
				Mesocycle 4	72.3 ± 1.6	5111 ± 174	70.7 ± 2.2	-	152 ± 15	-	-	-
				Mesocycle 5	63.6 ± 2.4	4474 ± 137	71.0 ± 2.1	-	92 ± 7	-	-	-
				Mesocycle 6	71.7 ± 1.8	5232 ± 123	73.2 ± 1.7	-	163 ± 15	-	-	-
				Mesocycle 7	75.5 ± 1.7	5042 ± 71	67.2 ± 1.9	-	134 ± 10	-	-	-
				Mesocycle 8	74.5 ± 1.2	5150 ± 113	69.3 ± 1.3	-	158 ± 15	-	-	-
				Mesocycle 9	72.9 ± 1.8	5027 ± 204	69.0 ± 2.1	-	145 ± 16	-	-	-
				Mesocycle 10	73.3 ± 1.3	4545 ± 112	62.2 ± 1.6	-	139 ± 15	-	-	-
Oliveira et al. (2019b)	13 Premier Liga Players (Champions League team)	Average data from 1 game per week microcycles	GPS 10 Hz				Speed Zones =	14–18.9 km.hr^{-1}	19–23.9 km.hr^{-1}	>24 km.hr^{-1}		
				MD-4	37 ± 7	6689 ± 293	-	789 ± 139	243 ± 28	87 ± 0	-	-
				MD-3	61 ± 3	5388 ± 1208	-	563 ± 255	163 ± 98	31 ± 36	-	-
				MD-2	77 ± 0	6709 ± 483	-	765 ± 182	255 ± 66	25 ± 6	-	-
				MD-1	76 ± 0	2735 ± 407	-	120 ± 56	17 ± 17	3 ± 3	-	-
Kelly et al. (2020)	26 English Premier League Players	Average load for each lead in day over an entire in season	GPS 15 Hz				Speed Zones =	>14.4 km.hr^{-1}	19.8–25.2 km.hr^{-1}			
				MD+2	-	3713 ± 1455	-	498 ± 516	132 ± 131	-	-	-
				MD-4	-	3977 ± 1850	-	483 ± 674	141 ± 168	-	-	-
				MD-3	-	4190 ± 1648	-	560 ± 596	167 ± 149	-	-	-
				MD-2	-	3407 ± 1415	-	436 ± 492	132 ± 126	-	-	-
				MD-1	-	2763 ± 1200	-	322 ± 412	92 ± 106	-	-	-
Oliveira et al. (2020)	20 Premier Liga Players (Champions League team)	Average lead in data after a win, draw or loss in the preceding fixture	GPS 10 Hz			r	Speed Zones =		>19 km.hr^{-1}			
				MD-5 (Win)	56 ± 1	7006 ± 149	126 ± 4.2	-	279 ± 21	-	-	-
				MD-5 (Draw)	30 ± 1	7112 ± 99	122 ± 4	-	284 ± 18	-	-	-
				MD-5 (Loss)	65 ± 2	7326 ± 83	116 ± 5	-	295 ± 25	-	-	-
				MD-4 (Win)	81 ± 1	6468 ± 90	80 ± 1	-	291 ± 18	-	-	-
				MD-4 (Draw)	82 ± 1	6375 ± 83	80 ± 1	-	274 ± 14	-	-	-
				MD-4 (Loss)	79 ± 2	6187 ± 110	78 ± 2	-	240 ± 14	-	-	-
				MD-3 (Win)	80 ± 1	6724 ± 102	84 ± 1	-	241 ± 16	-	-	-
				MD-3 (Draw)	78 ± 1	6700 ± 13	87 ± 3	-	233 ± 22	-	-	-
				MD-3 (Loss)	76 ± 1	7109 ± 142	94 ± 3	-	307 ± 15	-	-	-
				MD-2 (Win)	80 ± 1	5649 ± 59	73 ± 1	-	216 ± 11	-	-	-
				MD-2 (Draw)	69 ± 1	5577 ± 138	81 ± 2	-	160 ± 19	-	-	-
				MD-2 (Loss)	88 ± 2	6109 ± 86	70 ± 1	-	226 ± 16	-	-	-
				MD-1 (Win)	85 ± 1	3629 ± 58	43 ± 1	-	86 ± 7	-	-	-
				MD-1 (Draw)	95 ± 2	3391 ± 153	36 ± 2	-	131 ± 18	-	-	-
				MD-1 (Loss)	92 ± 2	3236 ± 113	36 ± 2	-	55 ± 7	-	-	-
				MD+1 (Win)	19 ± 1	4419 ± 69	250 ± 13	-	109 ± 11	-	-	-
				MD+1 (Draw)	15 ± 0	4394 ± 62	259 ± 10	-	105 ± 10	-	-	-
				MD+1 (Loss)	17 ± 1	4345 ± 108	277 ± 13	-	96 ± 11	-	-	-

(*Continued*)

Table 1. (Continued).

Reference	Subjects	Notes	System Used	Position/Type of Session/Phase of the Season	Duration (mins)	Total Distance (m)	Meters Per minute (m/min)	Running Distance (m)	High Speed Running (m)	Sprinting (m)	Accels	Decels
Chena et al. (2021)	22 Spanish La Liga players	Average load for each lead in day over an entire in season	GPS 10 Hz				Speed Zones =		>21 km. hr^{-1}		>2.5 m/s^2	>2.5 m/s^2
				MD-4	-	5261 ± 636	-	-	174 ± 83	-	70 ± 14	73 ± 11
				MD-3	-	5890 ± 588	-	-	314 ± 58	-	52 ± 9	57 ± 8
				MD-2	-	3125 ± 593	-	-	99 ± 68	-	29 ± 6	31 ± 6
				MD-1	-	3725 ± 475	-	-	183 ± 48	-	37 ± 4	38 ± 5
Oliveira et al. (2021)	20 Premier Liga Players (Champions League team)	Average lead in data after a home or away match	GPS 10 HZ				Speed Zones =		>19 km. hr^{-1}			
				MD-5 (Home)	57 ± 3	7051 ± 168	130 ± 6	-	254 ± 19	-	-	-
				MD-5 (Away)	58 ± 2	7211 ± 120	129 ± 5	-	316 ± 28	-	-	-
				MD-4 (Home)	81 ± 1	6156 ± 95	76 ± 1	-	252 ± 18	-	-	-
				MD-4 (Away)	77 ± 1	6520 ± 124	84 ± 2	-	273 ± 17	-	-	-
				MD-3 (Home)	81 ± 1	6644 ± 112	82 ± 1	-	236 ± 13	-	-	-
				MD-3 (Away)	79 ± 1	6864 ± 66	88 ± 1	-	238 ± 16	-	-	-
				MD-2 (Home)	78 ± 1	5672 ± 67	73 ± 1	-	203 ± 10	-	-	-
				MD-2 (Away)	79 ± 0	5772 ± 58	73 ± 1	-	208 ± 12	-	-	-
				MD-1 (Home)	86 ± 1	3644 ± 62	42 ± 1	-	70 ± 7	-	-	-
				MD-1 (Away)	83 ± 1	3452 ± 67	42 ± 1	-	69 ± 5	-	-	-
				MD+1 (Home)	26 ± 3	4421 ± 114	102 ± 16	-	103 ± 17	-	-	-
				MD+1 (Away)	16 ± 1	4308 ± 82	273 ± 12	-	78 ± 9	-	-	-

GPS = Global Positioning Systems, CD = Central Defenders, WD = Wide Defenders, CM = Central Midfielders, WM = Wide Midfielders, ATT = Attackers, HI = High Intensity Session, LI = Low Intensity Session, MD = Match Day, C = Conditioning, R = Recovery, Accels = Accelerations, Decels = Decelerations, – = No data available

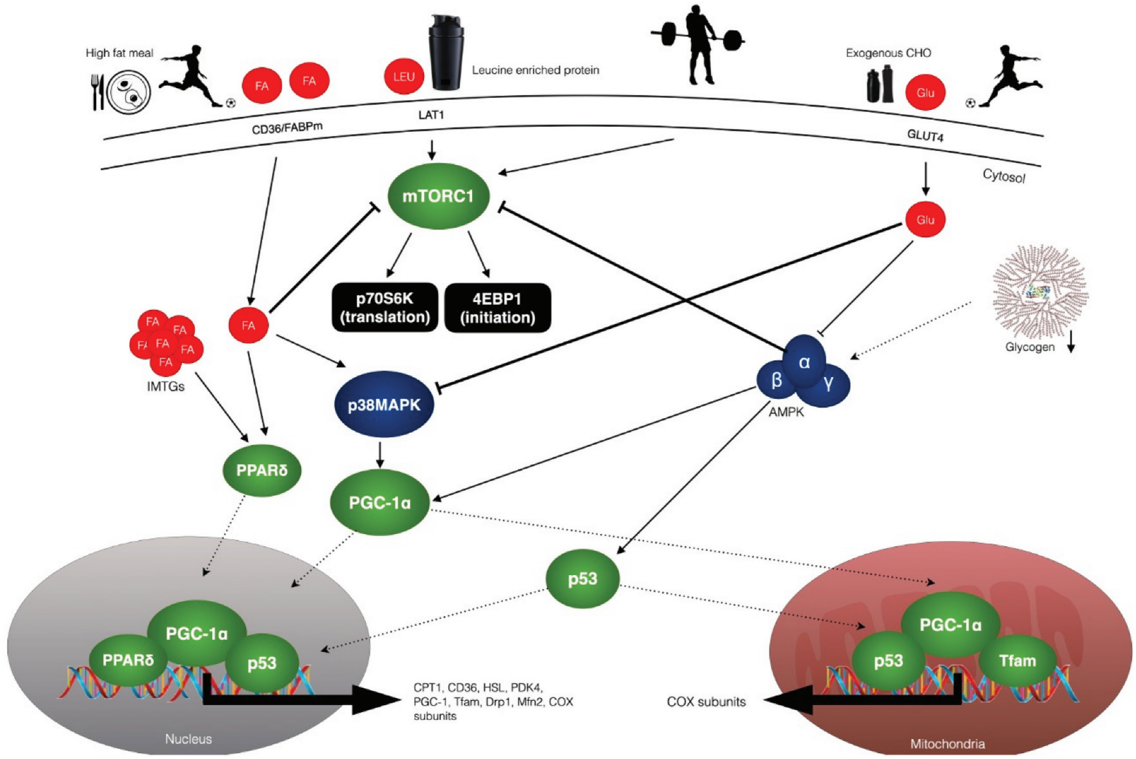

Figure 2. Schematic overview of the potential exercise-nutrient sensitive cell signalling pathways regulating the enhanced mitochondrial adaptations associated with training with low CHO availability. Reduced muscle glycogen enhances both AMPK and p38MAPK phosphorylation that results in activation and translocation of PGC-1α to the mitochondria and nucleus. Upon entry into the nucleus, PGC-1α co-activates additional transcription factors, (i.e. NRF1/2) to increase the expression of COX subunits and Tfam as well as autoregulating its own expression. In the mitochondria, PGC-1α co-activates Tfam to coordinate regulation of mtDNA and induces expression of key mitochondrial proteins of the electron transport chain, e.g., COX subunits. Similar to PGC-1α, p53 activity is also increased in response to exercise in conditions of low CHO availability upon which it translocates to the mitochondria to modulate Tfam activity and mtDNA expression and to the nucleus where it functions to increase expression of proteins involved in mitochondrial fission and fusion (DRP-1 and MFN-2) and electron transport chain protein proteins. Exercising in conditions of reduced CHO availability increases adipose tissue and intramuscular lipolysis via increasing circulating Adrenaline concentrations. The resulting elevation in FFA activates the nuclear transcription factor, PPARδ to increase expression of proteins involved in lipid metabolism such as CPT-1, PDK4, CD36 and HSL. However, consuming pre-exercise meals rich in CHO and/or CHO during exercise can down-regulate lipolysis (thereby negating FFA mediated signalling) as well as reducing both AMPK and p38MAPK activity thus having negative implications for downstream regulators. High fat feeding can also modulate PPARδ signalling and up-regulate genes with regulatory roles in lipid metabolism (and down regulate CHO metabolism) though high fat diets may also reduce muscle protein synthesis via impaired mTOR-p70S6K signalling, despite feeding leucine rich protein. Performing resistance training activates mTORC1, however, performing aerobic training within proximity may activate AMPK mediated signalling that impairs mTORC1 activation. **Abbreviations**: 4EBP1; eukaryotic translation initiation factor 4E-binding protein 1, AMPK; AMP-activated protein kinase, CHO; carbohydrate, COX; cytochrome c oxidase, CPT1; carnitine palmitoyltransferase 1, DRP1; dynamin-related protein 1, FA; fatty acids, FABP; fatty acid-binding protein, GLU; glucose, HSL; hormone-sensitive lipase, IMTG; intramuscular triglycerides, LAT1; large neutral amino acid transporter, LEU; leucine, Mfn2; mitofusion-2, mTORC1; mammalian target of rapamycin complex 1, p38 mitogen-activated protein kinase, p70S6K; ribosomal protein s6 kinase, PDK4; pyruvate dehydrogenase kinase 4, PGC-1α; peroxisome proliferator-activated receptor gamma coactivator 1-alpha, PPARδ; peroxisome proliferator-activated receptor, Tfam; transcription factor A.

professional male soccer players. It is our current opinion that daily CHO requirements should operate on a sliding scale of 3–8 g.kg^{-1} body mass (BM) depending on the specific training scenario, fixture schedule and player-specific training goals (see Table 2). Above all, it is hoped that our present viewpoint may stimulate further research to assess the efficacy of CHO periodization strategies for soccer players. We also consider that CHO periodization should not be practiced by youth (Hannon et al., 2021) or female players (Morehen et al., 2021)given the negative health and performance outcomes associated with reduced energy availability in these populations.

2. CHO requirements of soccer match play

2.1 Metabolic demands of soccer match play

Professional players typically cover distances of 10–13 km per match (Bloomfield et al., 2007) with the vast majority of this distance classified as low-to-moderate intensity speeds (speed 0–19.8 km.h^{-1}) (Bradley et al., 2009), whereas high-speed running (HSR) (speeds >19.8 km.h^{-1}) accounts for ~8% of total distance completed (Rampinini et al., 2007). Additionally, the physical and technical demands of match play are increasing such that high-intensity distance, sprint distance, number of sprints and successful passes per player have increased between the period of 2006–07 to 2012–13 (Barnes et al., 2014). Such developments in physical and technical demands further exemplify the requirement that sufficient CHO is available for skeletal muscle and the central nervous system during match play. In a cohort of Danish players, Krustrup et al. (2006) observed that pre-game muscle glycogen was 449 ± 23 mmol.kg^{-1} dw and decreased to 225 ± 23 mmol.kg^{-1} dw immediately after the match. Although post-game glycogen concentration in whole muscle would suggest sufficient glycogen available to continue exercising, analysis of individual muscle fibre types revealed that 50% of fibres could be classified as *empty* or *almost empty*. This pattern of depletion or near depletion was evident in type IIa and IIx fibres, the fibres responsible for sprinting and high-intensity activity. As such,

Table 2. Overview of suggested CHO requirements for male professional soccer players.

Training scenario	Typical daily external training load parameters(as quantified during pitch-based training according to GPS; HSR denotes high speed running = >19.8 km/h)	Suggested daily CHOrange	Comments
Pre-season training	Duration: 60–180 minTotal distance: 3–12 kmHSR: >400 m	4–8 g/kg BM	Suggested range accommodates likely variations in loads (e.g. potential twice per day sessions, recovery days) as well as individual training goals (e.g. manipulation of body composition to accommodate weight loss and fat loss or weight gain and lean mass gain). For example, twice per day training structures would likely require higher CHO intakes (e.g. 6–8 g/kg BM/day) whereas lower absolute intakes may be required where players are aiming for body fat loss or training intensity and duration is reduced (e.g. 4–6 g/kg BM/day).
In-season training (1 game per week)	Duration: 45–90 minTotal distance: 2–7 kmHSR: 0–400 m	3–8 g/kg BM	Suggested range accommodates likely variations in loads across the micro-cycle (e.g. low load days and MD-1 CHO loading protocols) as well as individual training goals (e.g. manipulation of body composition). For example, twice per day sessions, MD-1 and MD+1 would require higher CHO intakes (e.g. 6–8 g/kg BM/day) whereas lower absolute intakes may be required on other days of the week (e.g. 3–6 g/kg BM/day) depending on training intensity, duration and player-specific goals.
In-season training (Congested fixture periods)	Duration: <60 minTotal distance: <3 kmHSR: <50 m	6–8 g/kg BM	Suggested range accommodates the requirement to replenish muscle glycogen stores in the 48–72 h period between games. During this time, it is suggested that players consistently consume CHO within this range so as to promote glycogen availability.
Off-season training	N/A	<4 g/kg BM	Suggested intake accommodates the cessation of normal training loads, to avoid gains in fat mass. Note, for players who may be undergoing higher training loads (e.g. off-season training programmes CHO intake should be increased accordingly.

CHO = Carbohydrates, GPS = Global Positioning Systems, HSR = High Speed Running, BM = Body Mass

muscle and liver glycogen depletion are commonly cited as a contributing factor for the progressive reduction in high intensity running and sprinting that occurs throughout the course of a game (Mohr et al., 2003).

2.2 CHO requirements on match day minus 1 (MD-1)

Given the role of muscle glycogen in promoting high-intensity intermittent exercise performance (Balsom et al., 1999; Saltin, 1973), the major goal of nutritional interventions in the day prior to the game (often referred to as match day −1) is to maximise muscle glycogen stores (i.e., CHO loading). Professional players are likely to achieve high glycogen stores with 24 h of a CHO rich diet (Bussau et al., 2002) providing that training intensity and duration is significantly reduced on MD-1 (Anderson et al., 2015; Malone et al., 2015; Martin-Garcia et al., 2018; Stevens et al., 2017). To help promote muscle glycogen storage, it is recommended that players consume larger portion sizes and frequency of high glycaemic index foods and drinks (Burke et al., 1996, 1993), where daily intakes should equate to at least 6–8 $g.kg^{-1}$. It is noteworthy, however, that professional players from the English Premier League (EPL) are reported to only consume 4 $g.kg^{-1}$ on MD-1 (see Figure 3), values that may reduce total distance covered on match day when compared with 8 $g.kg^{-1}$ (Souglis et al., 2013). Despite such clear rationale, we acknowledge that further research is required to verify the glycogen cost of match play in elite professional players as well as the associated effects of muscle glycogen availability on physical and technical performance during match play.

2.3. CHO requirements for the pre-match meal

Assuming that players have correctly loaded muscle glycogen on MD-1, the role of the pre-match meal should be primarily to promote liver glycogen storage prior to match play, a goal that

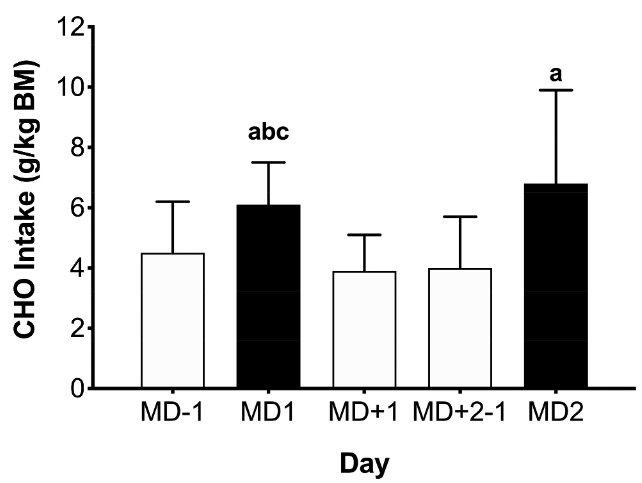

Figure 3. Daily carbohydrate intake in professional players from the EPL over a 5-day testing period which consisted of two competitive fixtures. White bars = training day and black bars = match day. a denotes difference from MD-1, b denotes difference from MD+1, c denotes difference from MD+2-1. CHO = carbohydrate, BM = body mass, MD = match day. Data redrawn from Anderson et al. (2017a).

becomes even more important for late morning or lunch-time kick-offs. Indeed, liver glycogen may be depleted by as much as 50% after an overnight fast and may not fully recover until early evening, dependent on the frequency and dose of CHO consumed (Iwayama et al., 2020). Despite the potential effects of pre-exercise CHO availability on performance, this has been largely under-researched in team sport athletes when compared with endurance athletes (Wu & Williams, 2006). Nonetheless, recent research from academy soccer players from the EPL demonstrates improved dribbling performance during the second half of a 90-min soccer match play simulation when a breakfast containing 80 g versus 40 g of CHO was consumed (Briggs et al., 2017). Whilst the timing of the pre-match meal changes according to kick-off time, it is still recommended that this meal be consumed approximately 3 hours before kick-off and contain 1–3 $g.kg^{-1}$ of CHO. Professional players from the EPL have been reported to consume CHO intakes equating to 1–1.5 $g.kg^{-1}$ in the pre-match meal, values that may be sub-optimal for performance when considered with insufficient CHO intakes on MD-1 (Anderson et al., 2017b).

2.4 In-Game CHO requirements

Carbohydrate feeding during exercise is likely to improve elements of match day performance when fed at a rate of 30–60 $g.hr^{-1}$ (Baker et al., 2015; Russell & Kingsley, 2014). Such ingestion rates improve physical aspects of performance such as total distance (Rodriguez-Giustiniani et al., 2019) and sprint distance (Harper et al., 2017) as well as technical actions such as passing (Currell et al., 2009), dribbling (Russell et al., 2012) and shooting (Russell et al., 2012). When considering the duration of the warm-up (e.g., 20–30 minutes) and match play itself (e.g., 90–95 minutes), this ingestion rate corresponds to an absolute dose of CHO equating to 60–120 g per game. Given the practical difficulties of fuelling during match play itself and that exogenous CHO oxidation rates are dependent on CHO feeding pattern (Mears et al., 2020), we suggest that players may benefit from CHO intake at the beginning (20–30 g) and end of the warmup period (20–30 g), the half-time period (20–40 g; an opportunity to consume a higher dose of CHO due to the increased time to consume whilst stationary) and if possible, the second half (20–30 g). We acknowledge, however, that such a feeding regimen (and indeed the optimal match day CHO strategy) has not been experimentally tested. Additionally, players should practice and refine their strategy during training and friendly games. From a format perspective, the provision of both CHO gels and sports drinks should be available for players to account for their individual preference during such times, especially when considering there is no difference between formats in relation to rates of exogenous CHO oxidation, gut comfort and exercise performance, albeit when tested during endurance exercise conditions (Guillochon & Rowlands, 2017; Pfeiffer et al., 2010). Similar to MD-1 and pre-match meal, we also observed that professional players from the EPL do not readily achieve in-game CHO guidelines (Anderson et al., 2017a).

2.5 Immediate post-game CHO requirements

In relation to acute muscle glycogen re-synthesis, the general consensus is that consuming 1.2 $g.kg^{-1}{\cdot}h^{-1}$ of high glycaemic CHO for 3–4 hours is optimal to facilitate short-term glycogen re-synthesis (Burke et al., 2016). Importantly, post-match feeding should begin immediately after match play (i.e., in the changing room) as this is when the muscle is most receptive to glucose uptake and glycogen synthesis (Ivy et al., 1988). In contrast to muscle, the optimal CHO feeding schedule to promote liver glycogen re-synthesis is not yet understood. Post-exercise ingestion of sucrose (5 hours of 1.2 $g.kg^{-1}{\cdot}h^{-1}$) is superior to matched doses of glucose in facilitating liver glycogen re-synthesis over a 6 h period in recovery from glycogen depleting endurance exercise (Fuchs et al., 2016). Although this feeding schedule is not directly applicable to the football player, such data suggest that fructose containing foods and drinks would be beneficial in acute recovery from match play. Despite the unequivocal evidence supporting an “hourly” CHO feeding schedule, post-match intake of CHO has also been identified as an area where players may not adhere to best practice guidelines, especially in recovery from evening games. For example, in recovery from a match commenced at 8:15 pm, EPL players reported consuming <1 $g.kg^{-1}{\cdot}h^{-1}$ in the initial 2 h recovery period whereas CHO intake across similar timescales in recovery from a 4:15 pm kick-off increased to 1–1.5 $g.kg^{-1}{\cdot}h^{-1}$ (Anderson et al., 2017b). Whilst no definitive reasons were reported, such differences between kick-off time may be due to the fact that players may not feel like eating or drinking after late night games and/or the logistical challenges of ensuring food availability during these times, especially in those instances where recovery corresponds with intense travel schedules.

2.6 Carbohydrate requirements on match day plus 1 (MD +1)

Given the time-course required to fully replenish muscle glycogen (i.e., 24–72 h exercise), there is also the requirement to consume adequate CHO on the day(s) after the match, often referred to by practitioners as MD+1. In the previously cited study, the EPL players were required to compete in another competitive game 72 h later and yet, daily CHO intake in the 48-h period between games was only 4 $g.kg^{-1}$ (Anderson et al., 2017a). Such data are considerably less than the range of 6–9 $g.kg^{-1}$ that has been documented to facilitate glycogen re-synthesis in a cohort of Danish players within 2–3 days of match play (Gunnarsson et al., 2013; Krustrup et al., 2011). Nonetheless, it should be noted that whilst recovery of glycogen appeared complete when assessed in whole muscle homogenate and type I fibres at 48 h post-match play, complete restoration of type II fibres was still not apparent (Gunnarsson et al., 2013). These data clearly highlight the need for high CHO intakes in recovery from match play, especially in those situations of two and three games per week microcycles (see Table 2).

3. CHO requirements of soccer training

3.1. Activity profile and glycogen utilization during soccer training

Despite more than four decades of research examining the physical demands of match play (Reilly & Thomas, 1976), detailed analysis of the customary training loads of elite soccer players is comparatively recent. With the advancements in Global Position System (GPS) technology, it is now commonplace for elite clubs to quantify the physical loads associated with training according to a variety of GPS metrics e.g., total distance, high-speed running, accelerations and decelerations (Akenhead et al., 2016; Anderson et al., 2016, 2015, 2017a; Malone et al., 2015; Martin-Garcia et al., 2018; Oliveira et al., 2020; Stevens et al., 2017). An overview of the in-season training load research is presented in Table 1. Such data demonstrate that the absolute training loads are not as high as those experienced in match play, as evidenced for total distance (e.g., <7.3 km vs. 10–14 km) (Bangsbo et al., 2006), high-speed running distance (e.g., <300 m v > 900 m) (Bradley et al., 2009) and sprint distance (e.g., <150 m v > 200 m) (Di Salvo et al., 2010). In contrast to match play where loading patterns is largely dependent on player position (Mohr et al., 2003), playing formation (Bradley et al., 2011) and technical ability (Bradley et al., 2010, 2013), the absolute daily loading during training is more complex and is dependent on a multitude of additional factors. For example, phase of the season (Malone et al., 2015; Oliveira et al., 2020), player position (Anderson et al., 2019b; Malone et al., 2015; Oliveira et al., 2020; Owen et al., 2017) coaching philosophy (Anderson et al., 2015; Malone et al., 2015), frequency of games (Anderson et al., 2015; Morgans et al., 2014a), player starting status (Anderson et al., 2016; Martin-Garcia et al., 2018) and player-specific training goals such as manipulation of body composition (Milsom et al., 2015) or rehabilitation from injury (Anderson et al., 2019a; Milsom et al., 2014) can all independently or collectively affect the total load accumulated over a weekly microcycle. Unlike match play, the glycogen cost associated with the habitual training loads completed by professional players have not yet been studied. In a soccer-simulated training protocol (based on motion analysis from training sessions completed by Korean professional soccer players) performed on a motorised treadmill, Jeong et al. (2015) reported glycogen depletion of only 20%, considerably less than the 50% depletion previously observed in match play studies (Krustrup et al., 2006). Although such protocols are limited due to omission of technical actions and changes of direction, etc., such data considered in combination with real-world training load data (see Table 1) suggest that the glycogen cost of training is likely not as great as match play.

3.2. CHO requirements for soccer training

On the basis of different physical loads associated with training and match play, we suggest that daily CHO and within day CHO distribution patterns should differ accordingly. Aside from the theoretical rationale of enhancing elements of training adaptation (as discussed below), CHO periodization strategies have a more straightforward and primary goal, that is, simply matching energy intake to energy demands. With this in mind, the principle of “fueling for the work required” is a practical framework to adjust CHO intake day-by-day and meal-by-meal according to the metabolic demands of the upcoming training sessions (Impey et al., 2016, 2018).

However, the rationale for practical application of CHO periodization strategies is further developed on the premise that commencing and/or recovering from exercise with reduced CHO availability up-regulates cell signaling pathways that regulate oxidative adaptations of human skeletal muscle, the result of which may culminate in enhanced training adaptations and improved exercise performance. It is noteworthy, however, that although numerous independent laboratories have demonstrated enhanced skeletal muscle adaptations associated with CHO periodization, such muscular adaptations do not always manifest as improved exercise performance outcomes (see Gejl & Nybo, 2021 for a recent meta-analysis). Additionally, it should also recognise that the majority of the research completed in this area has been completed using endurance training protocols where cycling is the most frequent exercise modality (see Impey et al., 2018 for a detailed review). Nonetheless, we previously observed that commencing high-intensity intermittent running (using a model aligned to the training-intensities associated with small sided games, i.e., 6 × 3 min bouts of running completed at 85–90% VO_{2max}) with reduced pre-exercise muscle glycogen (and without provision of CHO during exercise) augments training-induced up-regulation of oxidative enzyme activity in both the gastrocnemius and vastus lateralis muscle, as compared with conditions considered of normal pre-exercise muscle glycogen and consumption of CHO during training (Morton et al., 2009). It should also be noted, however, that many of the previous models of CHO periodization studied within the literature have incorporated models of CHO restriction that may not always be practically applicable to the professional player, e.g., training twice per day with limited recovery between sessions, training late in the evening followed by a fasted training session on the subsequent morning (the so-called sleep-low train-low model) etc. (see Impey et al., 2018; Burke et al., 2018 for a detailed discussion of such models).

It is noteworthy that professional players have reported limited evidence of CHO periodization across the weekly microcycle. For example, Brinkmens et al. (2019) reported daily CHO intakes of 3.9 $g.kg^{-1}$ and 3.7 $g.kg^{-1}$ in professional players from the Dutch Premier League on training and rest days, respectively, versus 5.1 $g.kg^{-1}$ on match days. Additionally, we also observed comparable CHO intakes of 4 $g.kg^{-1}$ in EPL players during training days (Anderson et al., 2017a) though such days were also indicative of MD-1 and MD+1, thus highlighting that nutritional preparation for match play may be sub-optimal (Burke et al., 2011). Whilst we acknowledge that the doubly labelled water (DLW) mediated assessments of energy expenditure (EE) does not provide day-to-day assessments, the energy expenditure (i.e., approximately 3000–3500 kcal/d, equivalent to ~48–55 $kcal.kg^{-1}$ LBM) reported in such studies (Anderson et al., 2017a; Brinkmens et al., 2019) nonetheless provides a basis for which to formulate daily CHO requirements. Indeed, given the daily protein recommendations for athletes (i.e. 1.6–2 $g.kg^{-1}$) and recommended fat intakes equivalent to 30% of total energy intake (Collins et al., 2021), it is reasonable to suggest that average daily CHO intakes of 3–6 $g.kg^{-1}$ during training days (that are not aligned to MD-1 or MD+1) would be sufficient to meet daily energy requirements that encompass the typical range in daily training intensity and duration associated with in-season training schedules.

3.3 Practical CHO periodization strategies for soccer players in a one game week

On the basis of the fuel for the work required approach and assessments of energy expenditure in professional players, we provide a theoretical overview of day-by-day and meal-by-meal CHO intakes as communicated using a red, amber, green (RAG) rating model (see Table 3). Given that the most frequent model of training for adult male professional players is a “morning” training session, our suggested model is based on commencing this on-field morning session with reduced CHO availability (if players complete two sessions per day or an evening training session, further models of CHO periodization could be

Table 3. Suggested practical model of the "fuel for the work required" CHO periodisation paradigm as applied to professional soccer players during a one game per week schedule.

	Typical Loads	Breakfast	During Training	Lunch	Snack(s)	Dinner
Monday (MD+2)	No Training	Medium CHO 0.5-1 g.kg^{-1}	NO TRAINING	Medium CHO 1 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}	Medium CHO 1 g.kg^{-1}
Tuesday (MD-4)	Duration = 70-80 mins TD = ~5000m HSR = <100m PM Resistance Training	Medium CHO 1 g.kg^{-1}	No CHO	High CHO 1.5-2 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}	Medium CHO 1 g.kg^{-1}
Wednesday (MD-3)	Duration = 80-90 mins TD = 6500m HSR = 300-600m	Medium CHO 1 g.kg^{-1}	No CHO	High CHO 1.5-2 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}
Thursday (MD-2)	Duration = <70 mins TD = <4500m HSR = <100m	Low CHO 0.5 g.kg^{-1}	No CHO	High CHO 1.5-2 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}
Friday (MD-1)	Duration = <60 mins TD = <3000m HSR = <50m	High CHO 2 g.kg^{-1}	High CHO 60 g.hr^{-1}	High CHO 2 g.kg^{-1}	High CHO 1.5 g.kg^{-1}	High CHO 2 g.kg^{-1}
		Breakfast	Pre-Match Meal	During Game	Post-Match	
Saturday (MD)	Duration = 90 mins TD ~11 km HSR = ~1000m	High CHO 2 g.kg^{-1}	High CHO 2 g.kg^{-1}	High CHO 60 g.hr^{-1}	High CHO 1.2 g.kg.hr^{-1} for 3 hours	
		Breakfast	During Training	Lunch	Snack	Dinner
Sunday = S (MD+1)	Recovery Session	High CHO 2 g.kg^{-1}	High CHO 60 g.hr^{-1}	High CHO 2 g.kg^{-1}	High CHO 1.5 g.kg^{-1}	High CHO 2 g.kg^{-1}
Sunday = NS (MD+1)	Duration = 70 Mins TD = ~6500m HSR = ~1200m	Medium CHO 0.5-1 g.kg^{-1}	No CHO	High CHO 1.5-2 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}

MD = Match Day, TD = Total Distance, HSR = High Speed Running, CHO = Carbohydrate, S = Starters (players who have completed >60 minutes of match play), NS = Non-starters (players who have completed <30 minutes of match play)

developed). In our chosen scenario, a one game per week microcycle is presented whereby daily CHO intake on training days is equivalent to 4 g.kg^{-1} but increased to 8 g.kg^{-1} on MD-1, MD and MD+1. In accordance with the lower physical loading on training days, CHO intake is reduced at breakfast and no CHO is consumed during training. On such days, the largest portion of CHO is consumed in the post-training meal (i.e., lunch) to facilitate glycogen re-synthesis and take advantage of the enhanced storage capacity in the initial 2 h period post-training (Ivy et al., 1988). Finally, CHO intake is reduced in the evening meal owing to the fact that the upcoming physical load on the subsequent day does not likely require high CHO availability to complete the desired training demands.

3.4 Practical CHO periodization strategies for soccer players in a two game week

With the growing demands of fixture congestion, professional players are often required to compete in two games per week. In such scenarios, attention should now be focused to increasing the muscle glycogen storage in preparation for games and optimally restoring muscle glycogen stores post-match play, a process that can take up to 72 h (Krustrup et al., 2011). Accordingly, we present a further theoretical framework where players are largely advised to consume a consistently high daily CHO intake across the weekly microcycle (e.g., 6–8 g.kg^{-1}) (see Table 4). Nonetheless, to avoid potential "over-fueling", it may be prudent for those players with specific training goals (e.g., reducing body fat) or non-starting players to also adhere to a moderate CHO intake on MD+2/MD-2 where intakes could range from 3 to 5 g.kg^{-1}, as dependent on individual circumstances. In periods of congested fixture schedules that may involve a 3 game per week schedule (e.g., the Christmas fixture period of the EPL), it is suggested that players would benefit from a consistently high daily CHO intake of 8 g.kg^{-1} so as to ensure sufficient glycogen availability for consecutive games.

Table 4. Suggested practical model of the "fuel for the work required" CHO periodisation paradigm as applied to professional soccer players during a two game per week schedule.

	Typical Loads	Breakfast	During Training	Lunch	Snack(s)	Dinner
Monday (MD+2/-1)	Duration = <45 minutes TD = <2000m HSR = <50m	High CHO 2 g.kg^{-1}	High CHO 60 g.hr^{-1}	High CHO 2 g.kg^{-1}	High CHO 1.5 g.kg^{-1}	High CHO 2 g.kg^{-1}
		Breakfast	Lunch	Pre-Match Meal	During Match	Post-Match
Tuesday (MD)	Duration = 90 mins TD ~11 km HSR = ~1000m	High CHO 2 g.kg^{-1}	High CHO 2 g.kg^{-1}	High CHO 2 g.kg^{-1}	High CHO 60 g.hr^{-1}	High CHO 1.2 g.kg.hr^{-1} for 3 hours (or until sleep)
		Breakfast	During Training	Lunch	Snack(s)	Dinner
Wednesday (MD+1)	Indoor Recovery Spin Bike = 20 minutes Foam Roll/ Massage = 20 minutes Pool = 20 minutes CWI = ~10 minutes	High CHO 2 g.kg^{-1}	High CHO 60 g.hr^{-1}	High CHO 2 g.kg^{-1}	High CHO 1.5 g.kg^{-1}	High CHO 2 g.kg^{-1}
Thursday (MD+2/-2)	Duration = <50 mins TD = <2500m HSR = <50m	Medium CHO 0.5-1 g.kg^{-1}	No CHO	High CHO 1.5 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}	Medium CHO 0.5-1 g.kg^{-1}
Friday (MD-1)	Duration = <60 mins TD = <3000m HSR = <50m	High CHO 2 g.kg^{-1}	High CHO 60 g.hr^{-1}	High CHO 2 g.kg^{-1}	High CHO 1.5 g.kg^{-1}	High CHO 2 g.kg^{-1}
		Breakfast	Pre-Match Meal	During Game	Post-Match	
Saturday (MD)	Duration = 90 mins TD ~11 km HSR = ~1000m	High CHO 2 g.kg^{-1}	High CHO 2 g.kg^{-1}	High CHO 60 g.hr^{-1}	High CHO 1.2 g.kg.hr^{-1} for 3 hours	
		Breakfast	During Training	Lunch	Snack	Dinner
Sunday = S (MD+1)	Recovery Session	High CHO 2 g.kg^{-1}	High CHO 60 g.hr^{-1}	High CHO 2 g.kg^{-1}	High CHO 1.5 g.kg^{-1}	High CHO 2 g.kg^{-1}

MD = Match Day, Dur = Duration, TD = Total Distance, HSR = High Speed Running, CWI = Cold Water Immersion, CHO = Carbohydrate, S = Starters (players who have completed >60 minutes of match play), NS = Non-starters (players who have completed <30 minutes of match play)

4. Concurrent training

4.1. Concurrent training in professional soccer

Soccer players require high levels of aerobic and anaerobic capacity and the ability to produce powerful match-specific movements (e.g., jumping, tackling, sprinting and accelerating) (Mohr et al., 2003; Wisloff et al., 2004). In addition to "on pitch" training, players therefore partake in strength-based training sessions in the gym setting (Walker & Hawkins, 2018). Training for both strength and endurance simultaneously is often referred to as "concurrent training" (Fyfe et al., 2014). For soccer players, the aerobic elements of match play are routinely developed using high-intensity sport-specific conditioning games/ drills and/or running drills, whereas maximal muscle strength and explosive power is developed and maintained using high-load resistance training (Morgans et al., 2014b; Silva et al., 2015; Walker & Hawkins, 2018). Nonetheless, due to constraints associated with available training time and competitive schedules (Anderson et al., 2015; Morgans et al., 2014b), professional players frequently perform both pitch and resistance sessions on the same day, usually with limited recovery and nutrition between sessions. However, our previous assessments of training habits from professional players demonstrate that soccer players often perform concurrent training in an "inconsistent" order with strength training either completed before or after soccer-specific training (Enright et al., 2017). As such, it is therefore important to consider how training order may influence the magnitude of training adaptation from both a strength and aerobic perspective. In this regard, the text to follow provides an initial overview of the proposed molecular signalling pathways regulating both strength and aerobic-type adaptations.

4.2. Molecular regulation of endurance versus strength training adaptations

It has been well documented that concurrent training can result in a compromised muscle strength and (or) power capacity (for greater detail see; Wilson et al., 2012). This blunted response in adaptation to strength training has been referred to as the "interference effect" (Hickson et al., 1980). From a molecular perspective, it is clear that strength training stimulates muscle protein synthesis (MPS) (Bodine et al., 2001; Drummond et al., 2009) via the activation of mammalian target of rapamycin complex 1 (mTORC1) pathway, whereas aerobic training adaptations (Saltin & Gollnick, 1983) are regulated via the proliferator-activated receptor gamma co-activator 1 α (PGC-1α) signalling axis (Perry et al., 2010; Pilegaard et al., 2003). Although the molecular pathways underpinning both aerobic and resistance training are becoming increasingly understood, the precise mechanisms underpinning the potential interference effect are still in their infancy.

A significant inhibitor of the Akt-mTOR pathway activation is frequently cited as AMP-activated protein kinase (AMPK) (Baar, 2014; Coffey & Hawley, 2017; Fyfe et al., 2014; Hawley, 2009), which when phosphorylated activates the downstream target PGC-1α (Puigserver & Spiegelman, 2003). AMPK is activated by a fall in ATP (concomitant with a rise in ADP and AMP), leading to an increase in the ADP/ATP ratio. As AMPK is phosphorylated there is an increase in the activation of tuberous sclerosis complex 1/2 (TSC1/2) which, in turn, is thought to cause the inhibition of mTORC1 signalling, most likely by the dephosphorylation of Raptor-mTOR (Baar, 2014; Coffey & Hawley, 2017; Fyfe et al., 2014; Hardie & Sakamoto, 2006; Hardie et al., 2016; Hawley, 2009; Sanchez et al., 2012; see Figure 2). In this way, the stimulation of the AMPK axis therefore has the potential to reduce the post-exercise MPS response, attenuating strength training adaptations (Baar, 2006). Nonetheless, such 'interferences' are not consistently observed as comparable improvements in resistance training adaptations have been found in concurrent versus resistance training alone (Cantrell et al., 2014; Glowacki et al., 2004; Laird et al., 2016; McCarthy et al., 1995; McCarthy et al., 2002). This apparent 'control' of the adaptive response may relate to the manipulation of variables such as exercise order (Cadore et al., 2012), between mode recovery duration (Lee et al., 2020), exercise modes (Moberg et al., 2021), training frequency, intensity, and volume (Fyfe et al., 2014; Murach & Bagley, 2016; Wilson et al., 2012) and nutrient availability (Camera et al., 2015). Moreover, compared to trained athletes, untrained individuals have a greater capacity to activate the molecular signalling responses to contractile activity as the stimulus induces large perturbations to cellular homeostasis (Benziane et al., 2008; Perry et al., 2010; Nader et al., 2014) and caution should be taken when interpreting research and applying it to elite athletic populations with an extensive training history.

4.3. Nutritional strategies for concurrent training

Given that muscle glycogen is the principal substrate during both high intensity aerobic-type activity and strength training (Bartlett et al., 2012; Hokken et al., 2021; Jeong et al., 2015), it is crucial that players have sufficient CHO availability prior to commencing both types of training sessions. Indeed, commencing aerobic exercise with reduced muscle glycogen concentration (<300 mmol.kg^{-1} dry weight) can influence the rate of whole-body protein synthesis, degradation and net balance during prolonged exercise (Howarth et al., 2010). In addition, commencing strength training in conditions of low muscle glycogen (<200 mmol.kg^{-1} dry weight) may reduce associated mTOR signalling (Churchley et al., 2007; Creer et al., 2005).

As commencing strength training with low levels of muscle glycogen can inhibit acute signalling mechanisms associated with MPS, it seems necessary to provide nutrient availability between sessions (or prior to resistance training exercise) to promote sufficient CHO availability. Although detailed scientific investigations examining this within a concurrent training model are scarce, Enright et al. (2015) undertook an ecologically valid investigation where participants underwent "real world" training sessions within the soccer environment. These researchers utilised an experimental design whereby EPL academy players performed concurrent training two-days per week over a 5-week period. One group performed strength training in the afternoon at 2 pm (approximately 1.5 h after lunch) after morning soccer training (commenced at 1030 am) and the other performed strength training in the morning (commenced at 930 am) prior to the soccer training. The researchers observed larger strength benefits when strength training was performed in the afternoon compared to the morning (e.g., 19.1% vs. 10.3% increase in half back squat). The authors suggested that the order of training (and associated alterations to pattern of signalling) may be a contributory factor underpinning the enhanced strength adaptation associated with afternoon strength training, although it was also acknowledged that the increased nutrient availability from the preceding meal (i.e., lunch) or a more evenly distributed macronutrient intake could also be a reason for the improvements in performance (Areta et al., 2013; Mamerow et al., 2014). Therefore, whilst manipulating the "order of training" within the concurrent training plan may affect adaptations, the daily distribution of energy and macronutrient intake of players may also play a modulatory role.

The energy cost of an acute strength training stimulus has been reported to have large variations of 2.3–11.0 kcal.min^{-1} (Reis et al., 2011). Reasons for such variations are related to the type of equipment that is used, number of exercises and repetitions, external load, execution time in various movement phases, exercise order and recovery time between sets. Therefore, the actual energy cost of the strength training sessions typically completed by soccer players is not yet known. However, commencing strength training with sufficient muscle glycogen is likely to positively impact cell signalling mechanisms associated with MPS and is the major fuel source for strength training, with an absolute glycogen cost of 100–250 mmol.kg^{-1} previously reported during high volume sessions (Robergs et al., 1991; Samuelson et al., 2016; Haff et al., 2003; Essén-Gustavsson & Tesch, 1990; MacDougal et al., 1999; Tesch et al., 1986; Pascoe et al., 1993; Hokken et al., 2021). Although glycogen utilisation of this magnitude is unlikely to cause depletion and fatigue (given that levels should be high to start with), an investigation into muscle glycogen utilisation within different fibre types identified that an acute bout of resistance exercise elicited a higher glycogen use by type 2 fibres than type 1, as documented in all subcellular storage pools (i.e., 47–54% vs. 8–33%, respectively). Moreover, there was a greater reduction in volumetric content of glycogen (72%) located within the myofibrils in type 2 fibres, reflecting near depleted amounts of intramyofibrillar glycogen (Hokken et al., 2020). Similar reductions in intramyofibrillar glycogen are associated with impaired excitation-contraction coupling and reduced contractile force production (Nielsen et al., 2014, 2009; Ørtenblad et al., 2011). On this basis, it is suggested that strength training should always be commenced with sufficient muscle glycogen concentration that actually permits completion of the desired workload as well as providing sufficient energy availability to modulate cell signalling associated with MPS.

4.3. Practical CHO strategies for soccer players in a concurrent training model

Given the role of muscle glycogen availability as a substrate for resistance exercise as well as the effects on cell signalling associated with MPS, it would therefore seem logical that soccer players should commence strength training sessions with sufficient glycogen stores (i.e., >300 mmol.kg^{-1} dry weight). Additionally, strength training should likely be performed several hours after soccer training when the acute metabolic stress from the prior soccer training has subsided. From a practical perspective (at least for players who perform on pitch soccer training in the morning), it would therefore seem pertinent to perform strength training in the afternoon following both recovery from morning soccer training and high CHO intake at lunch (i.e., >2 g.kg^{-1}). Additionally, CHO and protein should be consumed immediately post-resistance training to augment muscle glycogen resynthesis and ensure sufficient energy availability to promote MPS (Burd et al., 2009; van Loon et al., 2000). Given that concurrent training days involve twice per day training and hence a greater absolute energy demand, it is suggested that daily CHO intake should at least equate to 6 g.kg^{-1} body mass. Further experimental work (incorporating both mechanistic and functional outcomes) is now required to assess the optimal exercise order and feeding regimens for which to maximize concurrent training adaptations in soccer players.

5. CHO requirements for goalkeepers

5.1 Activity profile and metabolic demands of Goalkeepers (GKs)

The role of the GK is different to outfield players, with the primary responsibility to protect their teams goal and secondary, to distribute the ball to initiate an attack (White et al. , 2020). In competitive matches, GKs cover significantly less total distance (4–6 km vs. ~10–12 km) (Anderson et al., 2019b; Malone et al., 2018; Di Salvo et al., 2008) and high-speed running (<50 m vs. 1000 m) (Anderson et al., 2019b, 2017a; Bradley et al., 2010) than outfield players. However, rather than locomotive distances, the demands of a GK are mainly assessed on their ability to perform high-intensity movements and explosive actions (e.g., a dive to save the ball or a catch from a cross), which are usually separated by longer walking and jogging periods that allow for recovery (Ziv & Lidor, 2011). In addition to the movement demands, empirical observations suggest that GKs are often required to pass the ball >50 m into the opponents half, often equating to 8–14 kicks.match^{-1} (Hongyou et al., 2015). Therefore, it is clear from locomotive data and empirical evidence that physiological demands associated with technical actions are anaerobic in nature, interspersed with long periods of low-level aerobic activity such as walking and jogging. However, to the authors<apos;> knowledge, there is no data which has directly measured any physiological response to match play in GKs.

Given the unique positional demands that GKs are subjected to in match play, their training loads are required to incorporate similar movements and/or loading patterns. Goalkeepers<apos;> training is unique as they often train in small groups using position-specific training drills delivered by the GK coach, with some involvement in outfield player drills (e.g., tactical and small-sided games) (Malone et al., 2018). More recently, there has been an uprise in research regarding the training load of GKs, potentially due to an advancement in technology in the form of GK specific GPS units which generate data relating to specific GK movements (e.g., jumps, dives and dive returns) (Anderson et al., 2019b; Malone et al., 2018; White et al., 2020). Malone et al. (2018) examined the training load practices and the subsequent subjective wellness responses of a GK playing in the Dutch league. Here, this GK typically covered 2553–3742 m total distance and around 17% of the high-speed running of that typically observed by outfield players in training sessions. Observations of another GK from the EPL reported lower locomotive values (total distance of 1393–2422 m), potentially due to competing in 2 competitive matches within the weekly microcycle studied (Anderson et al., 2019b). These data provide some evidence of periodization as training is switched to recovery and preparation for the next match, instead of physical loading induced by training. In a comprehensive analysis of GK specific loading patterns, eight GKs were examined over an entire EPL season (White et al., 2020). White and colleagues reported that GK specific training (in terms of that conducted with the specific GK coach) elicited the highest load with an average of 51 dives, 14 high jumps, 19 medium jumps, 10 low jumps, 34 high-speed changes of direction and 70 explosive efforts performed during these parts of training. The authors stated that all these variables were considerably higher than match play.

Although no data exists on the physiological demands of GK training or match play, assessment of energy expenditure (via the DLW method) of a GK from the English Premier League observed that energy expenditure (n = 1, 2894 kcal.day^{-1}) is significantly less than outfield players from the same team (n = 6, 3566 kcal.day^{-1}) (Anderson et al., 2019b, 2017a), as studied during a two game per week microcycle. However, in a cohort of four GKs from the Dutch Eredivisie, energy expenditure was similar to that reported in outfield players (3365 ± 231 kcals^{-1}) over a 14-day period. These data are perhaps more reflective of the typical expenditure of GKs who are undertaking higher training loads (with more GK specific training) in 1 game per week microcycles.

5.2. CHO requirements for professional goalkeepers in match play and training

In studying a GK from the EPL, Anderson et al. (2019b) reported a daily CHO intake of 2.6 g.kg^{-1} on training days and 3.5 g.kg^{-1} on match days. These intakes were below that reported by Brinkmens et al. (2019) of 3.6 g.kg^{-1} CHO for four GKs in the Dutch Eredivisie league, although this was an average of both training and match days. Whilst we acknowledge that the DLW mediated assessment of EE does not provide day-to-day assessments, the EE (i.e., approximately 2894–3365 kcals^{-1}, equivalent to ~43 kcal.kg^{-1} LBM) reported in such studies (Anderson et al., 2019b; Brinkmens et al., 2019) provides a basis for which to formulate daily CHO requirements. Indeed, given the basis of a daily protein intake of 1.6–2 g.kg^{-1} and recommended fat intakes equivalent to 30% of total energy intake (Collins et al., 2021), it is reasonable to suggest that average daily CHO intakes of ~4 g.kg^{-1} during training days (that are not aligned to MD-1) and ~6 g.kg^{-1} for match days (inclusive of MD-1 and MD+1) would be sufficient to meet daily energy requirements that encompass the typical range in daily training intensity and duration associated with in-season training schedules. Indeed, sufficient CHO availability is required to maintain physical (Harper et al., 2017), cognitive (Pomportes et al., 2016) and technical (Currell et al., 2009) performance on both training and match days. Additionally, muscle glycogen is likely the predominant substrate for high volume resistance training (Hokken et al., 2021) completed on training days.

5.3 Practical CHO periodization strategies for a goalkeeper in a one game week

On the basis of training demands and the requirement to have sufficient levels of CHO availability during match play and training, we provide a practical theoretical overview of day-by-day and meal-by-meal CHO intake as communicated using a RAG rating model (see Table 5). This model is similar to that of outfield players, although the absolute values are lower on both training and match days due to the decreased demands. Additionally, GKs are recommended to consume a greater amount of CHO at breakfast given that strategic periodization of reduced CHO availability (so as to induce oxidative adaptations) is not likely required. On MD, MD-1 and MD+1, the largest amount of CHO is consumed, although intake is more evenly distributed throughout the day due to maintaining blood glucose and muscle and liver glycogen during match play. Finally, on MD+2 when there is no training, GKs could consume a lower absolute CHO intake to account for favourable changes in body composition and achieve likely energy balance (van Dam and Seidell, 2007). As with all the previous models proposed in this paper, we readily acknowledge that further research is required to characterise the energetic and

Table 5. Suggested practical model of the "fuel for the work required" CHO periodisation paradigm as applied to professional soccer goalkeepers during a one game per week schedule.

	Typical Loads	Breakfast	During Training	Lunch	Snack(s)	Dinner
Monday (MD+2)	No Training	Low CHO 0.5 $g.kg^{-1}$	NO TRAINING	Medium CHO 0.5-1 $g.kg^{-1}$	Low CHO 0.5 $g.kg^{-1}$	High CHO 1-1.5 $g.kg^{-1}$
Tuesday (MD-4)	Duration = 80-90 mins TD = <4000 m High Intensity Jump & Dive Aim PM Resistance Training	High CHO 1-1.5 $g.kg^{-1}$	No CHO	High CHO 1-1.5 $g.kg^{-1}$	Medium CHO 0.5-1 $g.kg^{-1}$	Medium CHO 0.5-1 $g.kg^{-1}$
Wednesday (MD-3)	Duration = 75-85 mins Kicking and Technical Aim TD = <4000 m	High CHO 1-1.5 $g.kg^{-1}$	No CHO	High CHO 1-1.5 $g.kg^{-1}$	Medium CHO 0.5-1 $g.kg^{-1}$	Medium CHO 0.5-1 $g.kg^{-1}$
Thursday (MD-2)	Duration = 70-80 mins TD = <3000 m Taper and Recovery Aim	High CHO 1-1.5 $g.kg^{-1}$	No CHO	High CHO 1-1.5 $g.kg^{-1}$	Medium CHO 0.5-1 $g.kg^{-1}$	Medium CHO 0.5-1 $g.kg^{-1}$
Friday (MD-1)	Duration = <60 mins TD = <2000m Reactive and Stimulative Aim	High CHO 1.5 $g.kg^{-1}$	Medium CHO 30 $g.hr^{-1}$	High CHO 1.5 $g.kg^{-1}$	Medium CHO 0.5-1 $g.kg^{-1}$	High CHO 1.5 $g.kg^{-1}$
		Breakfast	**Pre-Match Meal**	**During Game**	**Post-Match**	
Saturday (MD)	Duration = 90 mins TD ~6000m	High CHO 1.5 $g.kg^{-1}$	High CHO 1.5 $g.kg^{-1}$	Medium CHO 30 $g.hr^{-1}$	High CHO 1.2 $g.kg.hr^{-1}$ for 1-2 hours	
	Typical Loads	**Breakfast**	**During Training**	**Lunch**	**Snack(s)**	**Dinner**
Sunday (MD+1)	Resistance Training	High CHO 1.5 $g.kg^{-1}$	No CHO	High CHO 1.5 $g.kg^{-1}$	Medium CHO 0.5-1 $g.kg^{-1}$	High CHO 1.5 $g.kg^{-1}$

MD = Match Day, Dur = Duration, TD = Total Distance, CHO = Carbohydrate.

metabolic demands associated with the specific training sessions completed by GKs to support or refute the recommendations suggested here. Indeed, our suggestions are based on interpretations of the generic literature surrounding CHO availability and performance, as opposed to specific research completed on this unique population.

6. Summary and future directions for research

On the basis of different external loading patterns between soccer match play and training (as well as the periodization of training load across the weekly micro-cycle), the aim of the present paper was to provide a contemporary overview and theoretical framework of CHO periodization strategies for the professional soccer player. Our chosen model provides suggested daily ranges of CHO intake as well as meal-by-meal recommendations that aim to simultaneously promote match day performance, recovery and stimulation of oxidative training adaptations, the latter achieved through activation of potent skeletal muscle cell signaling pathways. Nonetheless, practical models of CHO periodization should be specific to the training structure (i. e., time of day, number of sessions etc.) of the specific environment. We readily acknowledge, however, that further work is required to verify the metabolic demands (and glycogen requirement) associated with the typical training sessions completed by professional players. Indeed, our suggested range of CHO intake is based on recent assessments of EE from professional players (via DLW), as opposed to the true CHO and glycogen cost of training. As such, the day-to-day fluctuations in muscle glycogen availability across the training microcycle is suggested as a targeted area for future research. Additionally, longitudinal studies are required to test the efficacy of any proposed CHO periodization strategy on soccer-specific training adaptations (including cellular, physiological and performance outcomes) versus the traditional approach of consistent daily CHO intakes. When considering that the first reports of the activity profile and metabolic demands of match appeared in the 1970s, it is clear that the challenge of evaluating the physiological demands of soccer training remains as exciting as ever.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

ORCID

Liam Anderson http://orcid.org/0000-0003-3130-355X
Barry Drust http://orcid.org/0000-0003-2092-6962
Graeme L. Close http://orcid.org/0000-0002-7210-9553
James P. Morton http://orcid.org/0000-0003-2776-2542

References

Akenhead, R., Harley, J. A., & Tweddle, S. P. (2016). Examining the external training load of an English Premier League football team with special reference to acceleration. *Journal of Strength and Conditioning Research*, *30*(9), 2424–2432. doi:10.1519/JSC.0000000000001343

Anderson, L., Close, G. L., Konopinski, M., Rydings, D., Milsom, J., Hambly, C., Speakman, J. R., Drust, B., & Morton, J. P. (2019a). Case study: Muscle atrophy, hypertrophy, and energy expenditure of a Premier League soccer player during rehabilitation from anterior cruciate ligament injury. *International Journal of Sports Nutrition and Exercise Metabolism*, *29*(5), 559–566. doi:10.1123/ijsnem.2018-0391

Anderson, L., Close, G. L., Morgans, R., Hambly, C., Speakman, J. R., Morton, J. P., & Morton, J. P. (2019b). Assessment of energy expenditure of a professional goalkeeper from the English Premier League using the doubly labeled water method. *International Journal of Sports Physiology and Performance*, *14*(5), 681–684. doi:10.1123/ijspp.2018-0520

Anderson, L., Naughton, R. J., Close, G. L., Di Michele, R., Morgans, R., Drust, B., & Morton, J. P. (2017b). Daily distribution of macronutrient intakes of professional soccer players from the English Premier League. *International Journal of Sports Nutrition and Exercise Metabolism*, *27*(6), 491–498. doi:10.1123/ijsnem.2016-0265

Anderson, L., Orme, P., Di Michele, R., Close, G. L., Milsom, J., Morgans, R., Drust, B., & Morton, J. P. (2016). Quantification of seasonal long physical load in soccer players with different starting status from the English Premier League: Implications for maintaining squad physical fitness. *International Journal of Sports Physiology and Performance*, *11*(8), 1038–1046. doi:10.1123/ijspp.2015-0672

Anderson, L., Orme, P., Di Michele, R., Close, G. L., Morgans, R., Drust, B., & Morton, J. P. (2015). Quantification of training load during one-, two- and three-game week schedules in professional soccer players from the English Premier League: Implications for carbohydrate periodization. *Journal of Sports Sciences*, *34* (9) , 1250–12509 doi:10.1080/02640414.2015.1106574.

Anderson, L., Orme, P., Naughton, R. J., Close, G. L., Milsom, J., Rydings, D., O'Boyle, A., Di Michele, R., Louis, J., Hambly, C., Speakman, J. R., Morgans, R., Drust, B., & Morton, J. P. (2017a). Energy intake and expenditure of professional soccer players of the English Premier League: Evidence of carbohydrate periodization. *International Journal of Sports Nutrition and Exercise Metabolism*, *27*(3), 228–238. doi:10.1123/ijsnem.2016-0259

Areta, J. L., Burke, L. M., Ross, M. L., Camera, D. M., West, D. W. D., Broad, E. M., & Coffey, V. G. (2013). Timing and distribution of protein ingestion during prolonged recovery from resistance exercise alters myofibrillar protein synthesis. *Journal of Physiology*, *591*(9), 2319–2331. doi:10.1113/jphysiol.2012.244897

Baar, K. (2006). Training for endurance and strength: Lessons from cell signaling. *Medicine and Science in Sport and Exercise*, *38*(11), 2293–2307. doi:10.1249/01.mss.0000233799.62153.19

Baar, K. (2014). Using molecular biology to maximize concurrent training. *Sports Medicine*, *44*(S2), 117–125. doi:10.1007/s40279-014-0252-0

Baker, L. B., Rollo, I., Stein, K. W., & Jeukendrup, A. E. (2015). Acute effects of carbohydrate supplementation on intermittent sports performance. *Nutrients*, *7*(7), 5733–5763. doi:10.3390/nu7075249

Balsom, P. D., Wood, K., Olsson, P., & Ekblom, B. (1999). Carbohydrate intake and multiple sprint sports: With special reference to football (soccer). *International Journal of Sports Medicine*, *20*(1), 48–52. doi:10.1055/s-2007-971091

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences*, *24*(7), 665–674. doi:10.1080/02640410500482529

Bangsbo, J., Nørregaard, L., & Thorsøe, F. (1992). The effect of carbohydrate diet on intermittent exercise performance. *International Journal of Sports Medicine*, *13*(2), 152–157. doi:10.1055/s-2007-1021247

Barnes, C., Archer, D. T., Hogg, B., Bush, M., & Bradley, P. S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine*, *35*(13), 1095–1100. doi:10.1055/s-0034-1375695

Bartlett, J. D., Hawley, J. A., & Morton, J. P. (2015). Carbohydrate availability and exercise training adaptation: Too much of a good thing? *European Journal of Sports Science*, *15*(1), 3–12. doi:10.1080/17461391.2014.920926

Bartlett, J. D., Hwa Joo, C., Tae-Seok, J., Louhelainen, J., Cochran, A. J., Gibala, M. J., Gregson, W., Close, G. L., Drust, B., & Morton, J. P. (2012). Matched work high-intensity interval and continuous running induce similar increases in PGC-1 α mRNA, AMPK, p38, and p53 phosphorylation in human skeletal muscle. *Journal of Applied Physiology (1985)*, *112*(7), 1135–1143. doi:10.1152/japplphysiol.01040.2011

Benziane, B., Burton, T. J., Scanlan, B., Galuska, D., Canny, B. J., Chibalin, A. V., Zierath, J. R., & Stepto, N. K. (2008). Divergent cell signalling after short-term intensified endurance training in human skeletal muscle. *American Journal of Physiology. Endocrinology and Metabolism*, *295*(6), 1427–1438. doi:10.1152/ajpendo.90428.2008

Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Physical demands of different positions in FA Premier League Soccer. *Journal of Sports Science & Medicine*, *6*(1), 63–70. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3778701/

Bodine, S. C., Stitt, T. N., Gonzalez, M., Kline, W. O., Stover, G. L., Bauerlein, R., Zlotchenko, E., Scrimgeour, A., Lawrence, J. C., Glass, D. J., & Yancopoulos, G. D. (2001). Akt/mTOR pathway is a crucial regulator of skeletal muscle hypertrophy and can prevent muscle atrophy in vivo. *Nature Cell Biology*, *3*(11), 1014–1119. doi:10.1038/ncb1101-1014

Bradley, P. S., Carling, C., Archer, D., Roberts, J., Dodds, A., Di Mascio, M., Paul, D., Gomez Diaz, A., Peart, D., & Krustrup, P. (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. *Journal of Sports Sciences*, *29*(8), 821–830. doi:10.1080/02640414.2011.561868

Bradley, P. S., Di Mascio, M., Peart, D., Olsen, P., & Sheldon, B. (2010). High-intensity activity profiles of elite soccer players at different performance levels. *Journal of Strength and Conditioning Research*, *24*(9), 2343–2351. doi:10.1519/JSC.0b013e3181aeb1b3

Bradley, P. S., Lago-Penas, C., Rey, E., & Gomez Diaz, A. (2013). The effect of high and low percentage ball possession on physical and technical profiles in English FA premier league soccer matches. *Journal of Sports Sciences*, *31*(12), 1261–1270. doi:10.1080/02640414.2013.786185

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences*, *27*(2), 159–168. doi:10.1080/02640410802512775

Briggs, M. A., Harper, L. D., McNamee, G., Cockburn, E., Rumbold, P. L. S., Stevenson, E. J., & Russell, M. (2017). The effects of an increased calorie breakfast consumed prior to simulated match-play in Academy soccer players. *European Journal of Sport Science*, *17*(7), 858–866. doi:10.1080/17461391.2017.1301560

Brinkmens, N. Y. J., Iedema, N., Plasqui, G., Wouters, L., Saris, W. H. M., van Loon, L. J. C., & van Dijk, J. W. (2019). Energy expenditure and dietary intake in professional football players in the Dutch Premier League: Implications for nutritional counselling. *Journal of Sports Sciences*, *16*(24) , 1–9 doi:10.1080/02640414.2019.1576256.

Burd, N. A., Tang, J. E., Moore, D. R., & Phillips, S. M. (2009). Exercise training and protein metabolism: Influences of contraction, protein intake, and sex-based differences. *Journal of Applied Physiology (1985)*, *106*(5), 1692–1701. doi:10.1152/japplphysiol.91351.2008

Burke, L. M., Collier, G. R., Davis, P. G., Fricker, P. A., Sanigorski, A. J., & Hargreaves, M. (1996). Muscle glycogen storage after prolonged exercise: Effect of the frequency of carbohydrate feedings. *American Journal of Clinical Nutrition*, *64*(1), 115–119. doi:10.1093/ajcn/64.1.115

Burke, L. M., Collier, G. R., & Hargreaves, M. (1993). Muscle glycogen storage after prolonged exercise: Effect of the glycemic index of carbohydrate. *Journal of Applied Physiology*, *75*(2), 1019–1023. doi:10.1152/jappl.1993.75.2.1019

Burke, L. M., Hawley, J. A., Jeukendrup, A., Morton, J. P., Stellingwerff, T., & Maughan, R. J. (2018). Toward a common understanding of diet-exercise strategies to manipulate fuel availability for training and competition preparation in endurance sport. *International Journal of Sports Nutrition and Exercise Metabolism*, *28*(5), 451–463. doi:10.1123/ijsnem.2018-0289

Burke, L. M., Hawley, J. A., Wong, S. H. S., & Jeukendrup, A. E. (2011). Carbohydrates for training and competition. *Journal of Sports Sciences*, *29*(sup1), 17–27. doi:10.1080/02640414.2011.585473

Burke, L. M., Loucks, A. B., & Broad, N. (2006). Energy and carbohydrate for training and recovery. *Journal of Sports Sciences*, *24*(7), 675–685. doi:10.1080/02640410500482602

Burke, L. M., van Loon, L. J. C., & Hawley, J. A. (2016). Postexercise muscle glycogen resynthesis in humans. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, *122*(5), 1055–1067. doi:10.1152/japplphysiol.00860.2016

Bussau, V. A., Fairchild, T. J., Rao, A., Steele, P., & Fournier, P. A. (2002). Carbohydrate loading in human muscle: An improved 1 day protocol. *European Journal of Applied Physiology*, *87*(3), 290–295. doi:10.1007/s00421-002-0621-5

Cadore, E. L., Izquierdo, M., Alberton, C. L., Pinto, R. S., Conceicao, M., Cunha, G., Radaelli, R., Bottaro, M., Trindade, G. T., & Kruel, L. F. M. (2012). Strength prior to endurance intra-session exercise sequence optimizes neuromuscular and cardiovascular gains in elderly men. *Experimental Gerontology*, *47*(2), 164–169. doi:10.1016/j.exger.2011.11.013

Camera, D. M., West, D. W. D., Phillips, S. M., Rerecich, T., Stellingwerff, T., Hawley, J. A., & Coffey, V. G. (2015). Protein ingestion increases myofibrillar protein synthesis after concurrent exercise. *Medicine and Science in Sports and Exercise*, *47*(1), 82–91. doi:10.1249/MSS.0000000000000390

Cantrell, G. S., Schilling, B. K., Paquette, M. R., & Murlasits, Z. (2014). Maximal strength, power, and aerobic endurance adaptations to concurrent strength and sprint interval training. *European Journal of Applied Physiology*, *114*(4), 763–771. doi:10.1007/s00421-013-2811-8

Chena M, Morcillo J Alfonso, Rodríguez-Hernández M Luisa, Zapardiel J Carlos, Owen A and Lozano D. (2021). The Effect of Weekly Training Load across a Competitive Microcycle on Contextual Variables in Professional Soccer. IJERPH, 18(10), 5091 10.3390/ijerph18105091

Churchley, E. G., Coffey, V. G., Pedersen, D. J., Shield, A., Carey, K. A., Cameron-Smith, D., & Hawley, J. A. (2007). Influence of preexercise muscle glycogen content on transcriptional activity of metabolic and myogenic genes in well-trained humans. *Journal of Applied Physiology (1985)*, *102*(4), 1604–1611. doi:10.1152/japplphysiol.01260.2006

Clemente, F. M., Owen, A., Serra-Olivares, J., Nikoladis, P. T., van der Linden, C. M., & Mendes, B. (2019). Characterization of the weekly external load profile of professional soccer teams from Portugal and the Netherlands. *Journal of Human Kinetics*, *66*(1), 155–164. doi:10.2478/hukin-2018-0054

Coffey, V. G., & Hawley, J. A. (2017). Concurrent exercise training: Do opposites attract? *Journal of Physiology*, *595*(9), 2883–2896. doi:10.1113/JP272270

Collins, J., Maughan, R. J., Gleeson, M., Bilsborough, J. C., Jeukendrup, J. E., Morton, J. P., Phillips, S. M., Armstrong, L., Burke, L. M., Close, G. L., Duffield, R., Larson-Meyer, E., Louis, J., Medina, D., Meyer, F., Rollo, I., Sundgot-Borgen, J., Wall, B. T., Boullosa, B., . . . McCall, A. (2021). UEFA expert group statement on nutrition in elite football. part 1: Current evidence to inform practical recommendations and future directions. *British Journal of Sports Medicine*, *55*(8), 416. doi:10.1136/bjsports-2019-101961

Creer, A., Gallagher, P., Slivka, D., Jemiolo, B., Fink, W., & Trappe, S. (2005). Influence of muscle glycogen availability on ERK1/2 and Akt signalling after resistance exercise in human skeletal muscle. *Journal of Applied Physiology (1985)*, *99*(3), 950–956. doi:10.1152/japplphysiol.00110.2005

Currell, K., Conway, S., & Jeukendrup, A. E. (2009). Carbohydrate ingestion improves performance of a new reliable test of soccer performance. *International Journal of Sports Nutrition and Exercise Metabolism*, *19*(1), 34–36. doi:10.1123/ijsnem.19.1.34

Dellal, A., Lago-Peñas, C., Rey, E., Chamari, K., & Orhant, E. (2013). The effects of a congested fixture period on physical performance, technical activity and injury rate during matches in a professional soccer team. *British Journal of Sports Medicine*, *49*(6), 390–394. doi:10.1136/bjsports-2012-091290

Di Salvo, V., Baron, R., Gonzalàlez-Haro, C., Gormasz, C., Pigozzi, F., & Bachl, N. (2010). Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. *Journal of Sports Sciences*, *28*(14), 1489–1494. doi:10.1080/02640414.2010.521166

Di Salvo, V., Benito, P. J., Calderon, F. J., Di Salvo, M., & Piozzi, F. (2008). Activity profiles of elite goalkeepers during football match-play. *Journal of Sports Medicine and Physical Fitness*, *48* (4) , 443–446. https://pubmed.ncbi.nlm.nih.gov/18997646/

Drummond, M. J., Dreyer, H. C., Fry, C. S., Glynn, E. L., & Rasmussen, B. B. (2009). Nutritional and contractile regulation of human skeletal muscle protein synthesis and mTORC1 signaling. *Journal of Applied Physiology*, *106*(4), 1374–1384. doi:10.1152/japplphysiol.91397.2008

Dupont, G., Nédélec, M., McCall, A., McCormack, D., Berthoin, S., & Wisløff, U. (2010). Effect of 2 soccer matches in a week on physical performance and injury rate. *American Journal of Sports Medicine*, *38*(9), 1752–1758. doi:10.1177/0363546510361236

Enright, K., Morton, J. P., Iga, J., & Drust, B. (2015). The effect of concurrent training organisation in youth elite soccer players. *European Journal of Applied Physiology*, *115*(11), 2367–2381. doi:10.1007/s00421-015-3218-5

Enright, K., Morton, J. P., Iga, J., & Drust, B. (2017). Implementing concurrent-training and nutritional strategies in professional football: A complex challenge for coaches and practitioners. *Science and Medicine in Football*, *1*(1), 65–73. doi:10.1080/24733938.2016.1263394

Essén-Gustavsson, B., & Tesch, P. A. (1990). Glycogen and triglyceride utilization in relation to muscle metabolic characteristics in men performing heavy-resistance exercise. *European Journal of Applied Physiology*, *61*(1–2), 5–10. doi:10.1007/BF00236686

Fuchs, C. J., Gonzalez, J. T., Beelen, M., Cermak, N. M., Smith, F. E., Thelwall, P. E., Taylor, R., Trenell, M. I., Stevenson, E. J., & van Loon, L. J. C. (2016). Sucrose ingestion after exhaustive exercise accelerates liver, but not muscle glycogen repletion compared with glucose ingestion in trained athletes. *Journal of Applied Physiology*, *1*(11), 1328–1334. doi:10.1152/japplphysiol.01023.2015

Fyfe, J. J., Bishop, D. J., & Stepto, N. K. (2014). Interference between concurrent resistance and endurance exercise: Molecular bases and the role of individual training variables. *Sports Medicine*, *44*(6), 743–762. doi:10.1007/s40279-014-0162-1

Gaudino, P., Iaia, F. M., Alberti, G., Strudwick, A. J., Atkinson, G., & Gregson, W. (2013). Monitoring training in elite soccer players: Systematic bias between running speed and metabolic power data. *International Journal of Sports Medicine*, *34*(11), 963–968. doi:10.1055/s-0033-1337943

Gaudino, P., Iaia, R. M., Strudwick, A. J., Hawkins, R. D., Alberti, G., Atkinson, G., & Gregson, W. (2015). Factors influencing perception of effort (session rating of perceived exertion) during elite soccer training. *International Journal of Sports Physiology and Performance*, *10*(7), 860–864. doi:10.1123/ijspp.2014-0518

Gejl K Degn and Nybo L. (2021). Performance effects of periodized carbohydrate restriction in endurance trained athletes – a systematic review and meta-analysis. J Int Soc Sports Nutr, 18(1), 10.1186/s12970-021-00435-3

Glowacki, S. P., Martin, S. E., Maurer, A., Baek, W., Green, J. S., & Crouse, S. F. (2014). Effects of resistance, endurance, and concurrent exercise on training outcomes in men. *Medicine and Science in Sports and Exercise*, *36* (12) , 2119–2127. doi:10.1249/01.MSS.0000147629.74832.52

Guillochon M and Rowlands D S. Solid, Gel, and Liquid Carbohydrate Format Effects on Gut Comfort and Performance. International Journal of Sport Nutrition and Exercise Metabolism, 27(3), 247–254. 10.1123/ijsnem.2016-0211

Gunnarsson, T. P., Bendiksen, M., Bischoff, R., Christensen, P. M., Lesivig, B., Madsen, K., Stephens, F., Greenhaff, P., Krustrup, P., & Bangsbo, J. (2013). Effect of whey protein- and carbohydrate-enriched diet on glycogen resynthesis during the first 48 h after a soccer game. *Scandinavian Journal of Medicine & Science in Sports*, *23*(4), 508–515. doi:10.1111/j.1600-0838.2011.01418.x

Haff, G. G., Lehmkuhl, M. J., McCoy, L. B., & Stone, M. H. (2003). Carbohydrate supplementation and resistance training. *Strength and Conditioning Research*, *17* (17) , 187–196 doi:10.1519/1533-4287(2003)017<0187:csart>2.0.co;2.

Hannon, M. P., Parker, L. J. F., Carney, D. J., McKeown, J., Speakman, J. R., Hambly, C., Drust, B., Unnithan, V. B., Close, G. L., & Morton, J. P. (2021). Energy requirements of male academy soccer players from the English Premier League. *Medicine and Science in Sports and Exercise*, *53*(1), 200–210. doi:10.1249/MSS.0000000000002443

Harber, M. P., Crane, J. D., Douglass, M. D., Weindel, K. D., Trappe, T. A., Trappe, S. W., & Fink, W. F. (2008). Resistance exercise reduces muscular substrates in women. *International Journal of Sports Medicine*, *29*(9), 719–725. doi:10.1055/s-2007-989442

Hardie, D. G., & Sakamoto, K. (2006). AMPK: A key sensor for fuel and energy status in skeletal muscle. *Physiology, (Bethesda)* 26(3), 48–60 doi:10.1016/j.tcb.2015.10.013.

Hardie, D. G., Schaffer, B. E., & Brunet, A. (2016). AMPK: An energy-sensing pathway with multiple inputs and outputs. *Trends in Cell Biology*, *26*(3), 190–201. doi:10.1016/j.tcb.2015.10.013

Harper, L. D., Stevenson, E. J., Rollo, I., & Russell, M. (2017). The influence of a 12% carbohydrate-electrolyte beverage on self-paced soccer-specific exercise. *Journal of Science and Medicine in Sport*, *20*(12), 1123–1129. doi:10.1016/j.jsams.2017.04.015

Hawley, J. A. (2009). Molecular responses to strength and endurance training: Are the incompatible?. *Applied Physiology, Nutrition, and Metabolism*, *34*(3), 355–361. doi:10.1139/H09-023

Hawley, J. A., & Morton, J. P. (2004). Ramping up the signal: Promoting endurance training adaptation in skeletal muscle by nutritional manipulation. *Clinical and Experimental Pharmacology & Physiology*, *41*(8), 608–613. doi:10.1111/1440-1681.12246

Hickson, R. C., Rosenkoetter, M. A., & Brown, M. M. (1980). Strength training effects on aerobic power and short-term endurance. *Medicine and Science in Sports and Exercise*, *12*(5), 336–339. doi:10.1249/00005768-198025000-00006

Hokken, R., Laugesen, S., Aagaard, P., Suetta, C., Frandsen, U., Ørtenblad, N., & Nielsen, J. (2021). Subcellular localization- and fibre type-dependent utilization of muscle glycogen during heavy resistance exercise in elite power and Olympic weightlifters. *Acta Physiologica*, *231*(2), e13561. doi:10.1111/apha.13561

Hongyou, L., Gómez, M. A., Lago-Peńas, C., Arias-Estero, J., & Stefani, R. (2015). Match performance profiles of goalkeepers of elite football teams. *International Journal of Sports Science & Coaching*, *10*(4), 669–682. doi:10.1260/1747-9541.10.4.669

Howarth, K. R., Phillips, S. M., MacDonald, M. J., Richards, D., Moreau, N. A., & Gibala, M. J. (2010). Effect of glycogen availability on human skeletal muscle protein turnover during exercise and recovery. *Journal of Applied Physiology (1985)*, *103*(2), 431–438. doi:10.1152/japplphysiol.00108.2009

Impey, S. G., Hammond, K. M., Shepherd, S. O., Sharples, A. P., Stewart, C., Limb, M., Smith, K., Philp, A., Jeromson, S., Hamilton, D. L., Close, G. L., & Morton, J. P. (2016). Fuel for the work required: A practical approach to amalgamating train-low paradigms for endurance athletes. *Physiological Reports*, *4*(10), e12803. doi:10.14814/phy2.12803

Impey, S. G., Hearris, M. A., Hammond, K. M., Bartlett, J. D., Louis, J., Close, G. G., & Morton, J. P. (2018). Fuel for the work required: A theoretical framework for carbohydrate periodization and the glycogen threshold hypothesis. *Sports Medicine*, *48*(5), 1031–1048. doi:10.1007/s40279-018-0867-7

Ivy, J. L., Katz, A. L., Cutler, C. L., Sherman, W. M., & Coyle, E. F. (1988). Muscle glycogen synthesis after exercise: Effect of time of carbohydrate ingestion. *Journal of Applied Physiology*, *64*(4), 1480–1485. doi:10.1152/jappl.1988.64.4.1480

Iwayama, K., Onishi, T., Maruyama, K., & Takahashi, H. (2020). Diurnal variation in the glycogen content of the human liver using 13 C MRS. *NMR in Biomedicine*, *33*(6), e4289. doi:10.1002/nbm.4289

Jeong, T. S., Bartlett, J. D., Joo, C. H., Louhelainen, J., Close, G. L., Morton, J. P., & Drust, B. (2015). Acute simulated soccer-specific training increases PGC-1α mRNA expression in human skeletal muscle. *Journal of Sports Sciences*, *33*(14), 1493–1503. doi:10.1080/02640414.2014.992937

Kelly, D., . M., Strudwick, A. J., Atkinson, G., Drust, B., & Gregson, W. (2020). Quantification of training and match-load distribution across a season in elite English Premier League soccer players. *Science and Medicine in Football*, *4*(1), 59–67. doi:10.1080/24733938.2019.1651934

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjer, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: Implications for sprint performance. *Physical Fitness and Performance*, *38* (6) , 1165–1174 doi:10.1249/01.mss.0000222845.89262.cd.

Krustrup, P., Ørtenblad, N., Nielsen, J., Nybo, L., Gunnarsson, T. P., Iaia, F. M., Madsen, K., Stephens, F., Greenhaff, P., & Bangsbo, J. (2011). Maximal voluntary contraction force, SR function and glycogen resynthesis during the first 72 h after a high-level competitive soccer game. *European Journal of Applied Physiology*, *111*(12), 2987–2995. doi:10.1007/s00421-011-1919-y

Laird, R. H., Elmer, D. J., Barberio, M. D., Salom, L. P., Lee, K. A., & Pascoe, D. D. (2016). Evaluation of performance improvements after either resistance training or sprint interval based concurrent training. *Journal of Strength & Conditioning Research*, *30*(11), 3057–3065. doi:10.1519/JSC.0000000000001412

Lee, M. J.-C., Ballantyne, J. K., Chagolla, J., Hopkins, W. G., Fyfe, J. J., Phillips, S. M., Bartlett, J. D., & Bishop, D. J. (2020). Order of same-day concurrent training influences some indices of power development, but not strength, lean mass, or aerobic fitness in healthy, moderately active men after 9 weeks of training. *PLoS ONE*, *15*(5), e0233134. doi:10.1371/journal.pone.0233134

MacDougal, J. D., Ray, S., Slae, D. G., McCartney, N., Lee, P., & Garner, S. (1999). Muscle substrate utilization and lactate production during weight-lifting. *Canadian Journal of Applied Physiology*, *24*(3), 209–215. doi:10.1139/h99-017

Malone, J. J., Di Michele, R., Morgans, R., Burgess, D., Morton, J. P., & Drust, B. (2015). Seasonal training-load quantification in elite English premier league soccer players. *International Journal of Sports Physiology and Performance*, *10*(4), 489–497. doi:10.1123/ijspp.2014-0352

Malone, J. J., Jaspers, A., Helsen, W. F., Merks, B., Frencken, W. G., & Brink, M. S. (2018). Seasonal training load and wellness monitoring in a professional soccer goalkeeper. *International Journal of Sports Physiology and Performance*, *13* (5) , 1–13 doi:10.1123/ijspp.2017-0472.

Mamerow, M. M., Mettler, J. A., English, K. L., Casperson, S. L., Arentson-Lantz, E., Sheffield-Moore, M., Layman, D. K., & Paddon-Jones, D. (2014). Dietary protein distribution positively influences 24-h muscle protein synthesis in healthy adults. *Journal of Nutrition*, *144*(6), 876–880. doi:10.3945/jn.113.185280

Martin-Garcia, A., Gómez Díaz, A., Bradley, P. S., Morera, F., & Casamichana, D. (2018). Quantification of a professional football team's external load using a microcycle structure. *Journal of Strength & Conditioning Research*, *32*(12), 3511–3518. doi:10.1519/JSC.0000000000002816

McCarthy, J. P., Agre, J. C., Graf, B. K., Pozniak, M. A., & Vailas, A. C. (1995). Compatibility of adaptive responses with combining strength and endurance training. *Medicine and Science in Sports and Exercise*, *27*(3), 429–436. doi:10.1249/00005768-199503000-00021

McCarthy, J. P., Pozniak, M. A., & Agre, J. C. (2002). Neuromuscular adaptations to concurrent strength and endurance training. *Medicine and Science in Sports and Exercise*, *34*(3), 511–519. doi:10.1097/00005768-200203000-00019

Mears, S. A., Boxer, B., Sheldon, D., Wardley, H., Tarnowski, C. A., James, L. J., & Hulston, C. J. (2020). Sports drink intake pattern affects exogenous carbohydrate oxidation during running. *Medicine and Science in Sports and Exercise*, *52*(9), 1976–1982. doi:10.1249/MSS.0000000000002334

Milsom, J., Barreira, P., Burgess, D. J., Iqbal, Z., & Morton, J. P. (2014). Case study: Muscle atrophy and hypertrophy in a premier league soccer player during rehabilitation from ACL injury. *International Journal of Sports Nutrition and Exercise Metabolism*, *24*(5), 543–552. doi:10.1123/ijsnem.2013-0209

Milsom, J., Naughton, R., O'Boyle, A., Iqbal, Z., Morgans, R., Drust, B., & Morton, J. P. (2015). Body composition assessment of English Premier League soccer players: A comparative DXA analysis of first team, U21 and U18 squads. *Journal of Sports Sciences*, *33*(17), 1799–1806. doi:10.1080/02640414.2015.1012101

Moberg, M., Apró, W., Cervenka, I., Ekblom, B., van Hall, G., Holmberg, H. C., Ruas, J. L., & Blomstrand, E. (2021). High-intensity leg cycling alters the molecular response to resistance exercise in the arm muscles. *Scientific Reports*, *11*(1), 6453. doi:10.1038/s41598-021-85733-1

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences*, *21*(7), 439–449. doi:10.1080/0264041031000071182

Morehem, C., Rosimus, C., Cavanagh, B. P., Hambly, C., Speakman, J. R., Elliot-Sale, K. J., Hannon, M. P., & Morton, J. P. (2021). Energy expenditure of female international standard soccer players. *Medicine and Science in Sports and Exercise*. *epub ahead of print*. 10.1249/MSS.0000000000002850

Morehen, C., Bradley, W. J., Clarke, J., Twist, C., Hambly, C., Speakman, J. R., Morton, J. P., & Close, G. L. (2016). The assessment of total energy expenditure during a 14-day in-season period of professional rugby league players using the Doubly Labelled Water method. *International Journal of Sport Nutrition and Exercise Metabolism*, *26*(5), 464–472. doi:10.1123/ijsnem.2015-0335

Morgans, R., Orme, P., Anderson, L., & Drust, B. (2014b). Principles and practices of training for soccer. *Journal of Sport and Health Science*, *3* (4), 251–257. doi:10.1016/j.jshs.2014.07.002

Morgans, R., Orme, P., Anderson, L., Drust, B., & Morton, J. P. (2014a). An intensive winter fixture schedule induces a transient fall in salivary IgA in English premier league soccer players. *Research in Sports Medicine*, *22*(4), 346–354. doi:10.1080/15438627.2014.944641

Morton, J. P., Croft, L., Bartlett, J. D., Maclaren, D. P. M., Reilly, T., Evans, L., McArdle, A., & Drust, B. (2009). Reduced carbohydrate availability does not modulate training-induced heat shock protein adaptations but does up regulate oxidative enzyme activity in human skeletal muscle. *Journal of Applied Physiology*, *106*(5), 1513–1521. doi:10.1152/japplphysiol.00003.2009

Murach, K. A., & Bagley, J. R. (2016). Skeletal muscle hypertrophy with concurrent exercise training: Contrary evidence for an interference effect. *Sports Medicine*, *46*(8), 1029–1039. doi:10.1007/s40279-016-0496-y

Nader, G. A., von Walden, F., Liu, C., Lindvall, J., Gutmann, L., Pistilli, E. E., & Gordon, P. M. (2014). Resistance exercise training modulates acute gene expression during human skeletal muscle hypertrophy. *Journal of Applied Physiology*, *116*(6), 693–702. doi:10.1152/japplphysiol.01366.2013

Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2014). Recovery in soccer: Part I – Post-match fatigue and time course of recovery. *Sports Medicine*, *43* (1) , 997–1015 doi:10.1007/s40279-012-0002-0.

Nielsen, J., Cheng, A. J., Ørtenblad, N., & Westerblad, H. (2014). Subcellular distribution of glycogen and decreased tetanic Ca $^{2+}$++ in fatigued single intact mouse muscle fibres. *Journal of Physiology*, *529*(9), 2003–2012. doi:10.1113/jphysiol.2014.271528

Nielsen, J., Schrøder, H. D., Rix, C. G., & Ørtenblad, N. (2009). Distinct effects of subcellular glycogen localization on tetanic relaxation time and endurance in mechanically skinned rat skeletal muscle fibres. *Journal of Physiology*, *587*(14), 3479–3690. doi:10.1113/jphysiol.2009.174862

Oliveira, R., Brito, J. P., Loureiro, N., Padinha, V., Ferreira, B., & Mendes, B. (2020). Does the distribution of the weekly training load account for the match result of elite professional soccer players? *Physiology & Behavior*, *225* (113118) , epub. doi:10.1016/j.physbeh.2020.113118

Oliveira R, Brito J Paulo, Loureiro N, Padinha V, Nobari H and Mendes B. (2021). Will Next Match Location Influence External and Internal Training Load of a Top-Class Elite Professional European Soccer Team?. IJERPH, 18 (10), 5229 10.3390/ijerph18105229

Oliveira, R., Brito, J. P., Martins, A., Mendes, B., Calvete, F., Carriço, S., Ferraz, R., & Marques, M. C. (2019b). In-season training load quantification of one-, two- and three-game week schedules in a top European professional soccer team. *Physiology & Behavior*, *201* Epub , 146–156. doi:10.1016/j.physbeh.2018.11.036

Oliveira, R., Brito, J. P., Martins, A., Mendes, B., Marinho, A., Ferraz, R., & Marques, M. C. (2019a). In-season internal and external training load quantification of an elite European soccer team. *PLoS ONE*, *14*(4), e0209393. doi:10.1371/journal.pone.0209393

Ørtenblad, N., Nielsen, J., Saltin, B., & Holmberg, H. C. (2011). Role of glycogen availability in sarcoplasmic reticulum Ca $^{2+}$++ kinetics in human skeletal muscle. *Journal of Physiology*, *589*(3), 711–725. doi:10.1113/jphysiol.2010.195982

Owen, A. L., Lago-Peñas, C., Gomez, M. A., Mendes, B., & Dellal, A. (2017). Analysis of a training mesocycle and positional quantification in elite European soccer players. *International Journal of Sports Science & Coaching*, *12*(5), 665–676. doi:10.1177/1747954117727851

Owen, A. L., Wong, D. P., Dunlop, G., Groussard, C., Kebsi, W., Dellal, A., Morgans, R., & Zouhal, H. (2014). High intensity training and salivary immunoglobulin-a responses in professional top-level soccer players: Effect of training intensity. *Journal of Strength and Conditioning Research*, *30*(9), 2460–2469. doi:10.1519/JSC.0000000000000380

Pascoe, D. D., Costill, D. L., Fink, W. J., Robergs, R. A., & Zachwieja, J. J. (1993). Glycogen resynthesis in skeletal muscle following resistance exercise. *Medicine and Science in Sports and Exercise*, *25*(3), 349–354. doi:10.1249/00005768-199303000-00009

Perry, C. G., Lally, J., Holloway, G. P., Heigenhauser, G. J. F., Bonen, A., & Spriet, L. L. (2010). Repeated transient mRNA bursts precede increases in transcriptional and mitochondrial proteins during training in human skeletal muscle. *Journal of Physiology*, *588*(23), 4795–4810. doi:10.1113/jphysiol.2010.199448

Pfeiffer B, Stellingwerff T, Zaltas E, and Jeukendrup A E. (2010). Oxidation of Solid versus Liquid CHO Sources during Exercise. Medicine & Science in Sports & Exercise, 42(11), 2030–2037. 10.1249/MSS.0b013e3181e0efc9

Philp A, Hargreaves M and Baar K. (2012). More than a store: regulatory roles for glycogen in skeletal muscle adaptation to exercise. American Journal of Physiology-Endocrinology and Metabolism, 302(11), E1343–E1351. 10.1152/ajpendo.00004.2012

Pilegaard, H., Saltin, B., & Neufer, P. D. (2003). Exercise induces transient transcriptional activation of the PGC-1alpha gene in human skeletal muscle. *Journal of Physiology*, *546*(3), 851–858. doi:10.1113/jphysiol.2002.034850

Pomportes, L., Brisswalter, J., Hays, A., & Davranche, K. (2016). Effect of carbohydrate intake on maximal power output and cognitive performances. *Sports (Basel)*, *4*(4), 49. doi:10.3390/sports4040049

Puigserver, P., & Spiegelman, B. M. (2003). Peroxisome proliferator-activated receptor-γ coactivator 1α (PGC-1α): Transcriptional coactivator and metabolic regulator. *Endocrine Reviews*, *24*(1), 78–90. doi:10.1210/er.2002-0012

Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007). Variation in top level soccer match performance. *International Journal of Sports Medicine*, *28*(12), 1018–1024. doi:10.1055/s-2007-965158

Reilly, T. (2007). The training process. In T. Reilly (Ed.), *The science of training-soccer: A scientific approach to developing strength, speed and endurance* (pp. 1–19). Routledge.

Reilly, T., & Thomas, V. (1976). A motion analysis of work rate in different positional roles in pro football match-play. *Journal of Human Movement Studies*, *2*, 87–97.

Reis, V. M., Júnior, R. S., Zajac, A., & Oliveira, D. R. (2011). Energy cost of resistance exercise: An update. *Journal of Human Kinetics*, *29A*(Special-Issue), 33–39. doi:10.2478/v10078-011-0056-3

Robergs, R. A., Pearson, D. R., Costill, D. D., Fink, W. J., Pascoe, D. D., Benedict, M. A., Lambert, C. P., & Zachweija, J. J. (1991). Muscle glycogenolysis during different intensities of weight-resistance exercise. *Journal of Applied Physiology*, *70*(4), 1700–1706. doi:10.1152/jappl.1991.70.4.1700

Rodriguez-Giustiniani, P., Rollo, I., Witard, O. C., & Galloway, S. D. R. (2019). Ingesting a 12% carbohydrate-electrolyte beverage before each half of a soccer match simulation facilitates retention of passing performance and improves high-intensity running capacity in academy players. *International Journal of Sports Nutrition and Exercise Metabolism*, *29* (4) , 397–405 doi:10.1123/ijsnem.2018-0214.

Russell, M., Benton, D., & Kingsley, M. (2012). Influence of carbohydrate supplementation on skill performance during a soccer match simulation. *Journal of Science and Medicine in Sport*, *15*(4), 348–354. doi:10.1016/j.jsams.2011.12.006

Russell, M., & Kingsley, M. (2014). The efficacy of acute nutritional interventions on soccer skill performance. *Sports Medicine*, *44*(7), 957–970. doi:10.1007/s40279-014-0184-8

Saltin, B. (1973). Metabolic fundamentals in exercise. *Medicine and Science in Sports*, *5*(3), 137–146. https://pubmed.ncbi.nlm.nih.gov/4270581/

Saltin, B., & Gollnick, P. D. (1983). Skeletal muscle adaptability: Significance for metabolism and performance. In L. D. Peachy, R. H. Adrian, & S. R. Gaiger (Eds.), *Handbook of physiology, skeletal muscle* (pp. 555–631). American Physiological Society.

Samuelson, H., Moberg, M., Apró, W., Ekblom, B., & Blomstrand, E. (2016). Intake of branched-chain or essential amino acids attenuates the elevation in muscle levels of PGC-1α4 mRNA caused by resistance exercise. *American Journal of Physiology. Endocrinology and Metabolism*, *311*(1), 246–251. doi:10.1152/ajpendo.00154.2016

Sanchez, A. M. J., Candau, R. B., Csibi, A., Pagano, A. F., Raibon, A., & Bernardi, H. (2012). The role of AMP-activated protein kinase in the coordination of skeletal muscle turnover and energy homeostasis. *American Journal of Physiology – Cell Physiology*, *303*(5), 475–485. doi:10.1152/ajpcell.00125.2012

Silva, J. R., Nassis, G. P., & Rebelo, A. (2015). Strengthj training in soccer with a specific focus on highly trained players. *Sports Medicine - Open*, *1*(1), 17. doi:10.1186/s40798-015-0006-z

Souglis, A. G., Chryssanthopoulos, C. I., Travlos, A. K., Zorzou, A. E., Gissis, I. T., Papadopoulos, C. N., & Sotiropoulos, A. A. (2013). The effect of high vs. low carbohydrate diets on distances covered in soccer. *Journal of Strength and Conditioning Research*, *27*(8), 2235–2247. doi:10.1519/JSC.0b013e3182792147

Stellingwerff, T., Morton, J. P., & Burke, L. M. (2019). A framework for periodized nutrition for athletics. *International Journal of Sports Nutrition and Exercise Metabolism*, *29*(2), 141–151. doi:10.1123/ijsnem.2018-0305

Stevens, T. G. A., de Ruiter, C. J., Twisk, J. W. R., Savelsbergh, G. J. P., & Beek, P. J. (2017). Quantification of in-season training load relative to match load in professional Dutch Eredivisie football players. *Science and Medicine in Football*, *1*(2), 117–125. doi:10.1080/24733938.2017.1282163

Tesch, P. A., Colliander, E. B., & Kaiser, P. (1986). Muscle metabolism during intense, heavy resistance exercise. *European Journal of Applied Physiology*, *55*(4), 362–366. doi:10.1007/BF00422734

van Dam R M and Seidell J C. (2007). Carbohydrate intake and obesity. Eur J Clin Nutr, 61(S1), S75–S99. 10.1038/sj.ejcn.1602939

van Loon, L. J., Saris, W. H., Kruijshoop, M., & Wagenmakers, A. J. (2000). Maximizing postexercise muscle glycogen synthesis: Carbohydrate supplementation and the application of amino acid or protein hydrolysate mixtures. *American Journal of Clinical Nutrition*, *72*(1), 106–111. doi:10.1093/ajcn/72.1.106

Walker, G. J., & Hawkins, R. (2018). Structuring a program in elite professional soccer. *Strength and Conditioning Journal*, *40*(3), 72–82. doi:10.1519/SSC.0000000000000345

White, A., Hills, S. P., Hobbs, M., Cooke, C. B., Kilduff, L. P., Cook, C., Roberts, C., & Russell, M. (2020). The physical demands of professional soccer goalkeepers throughout a week-long competitive microcycle and transiently throughout match-play. *Journal of Sports Sciences*, *38*(8), 848–854. doi:10.1080/02640414.2020.1736244

Wilson, J. M., Marin, P. J., Rhea, M. R., Wilson, S. M., Loenneke, J. P., & Anderson, J. C. (2012). Concurrent training: A meta-analysis examining interference of aerobic and resistance exercises. *Journal of Strength & Conditioning Research*, *26*(8), 2293–2307. doi:10.1519/JSC.0b013e31823a3e2d

Wisloff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, *38*(3), 285–288. doi:10.1136/bjsm.2002.002071

Wu, C. L., & Williams, C. (2006). A low glycemic index meal before exercise improves endurance running capacity in men. *International Journal of Sports Nutrition and Exercise Metabolism*, *16*(5), 510–527. doi:10.1123/ijsnem.16.5.510

Ziv, G., & Lidor, R. (2011). Physical characteristics, physiological attributes, and performances of soccer goalkeepers. *International Journal of Sports Physiology and Performance*, *6*(4), 509–524. doi:10.1123/ijspp.6.4.509