QUANTIFICATION OF PHYSICAL LOADING, ENERGY INTAKE AND EXPENDITURE IN ENGLISH PREMIER LEAGUE SOCCER PLAYERS

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ABSTRACT

The physical demands of soccer match play have been extensively studied. Muscle glycogen is the major energy source required to meet these demands and strategies to maximise this provide clear performance benefits to match play. Such information has allowed sports nutritionists to develop specific guidelines to optimise physical performance and recovery. However, the physical demands of soccer training have only recently started to be examined. For this reason, Study 1 quantified training load in English Premier League soccer players (n=12) during one, two and three game weekly micro-cycles of the 2013-2014 season. Study 1 identified soccer training being significantly less than match play and identified that soccer training displayed evidence of training periodisation.

Having identified typical training load during the weekly micro-cycle, it was recognised that soccer match play comprises a large portion of the weekly physical load. Accordingly, Study 2 quantified differences in season long physical load (inclusive of both training and match play) between players who were classified as starters (n=8, started ≥60% of games), fringe players (n=7, started 30-60% of games) and non-starters (n=4, started <30% of games). Study 2 identified that unlike total seasonal volume of training (i.e. total distance and duration), seasonal high-intensity loading patterns are dependent on players' match starting status thereby having potential implications for training programme design and prescription of player-specific nutritional guidelines.

Additionally, daily energy expenditures (EE) and energy intakes (EI) of elite players are also not currently known. Therefore, studies 3, 4 and 5 quantified EE and EI in English Premier League soccer players consisting of outfield positions (n=6), a professional GK (n=1) and a player undergoing a rehabilitation period from an ACL reconstruction (n=1), respectively. Studies 3 and 4 were conducted over a 7-day period of the 2015-2016 season, consisting of two match days (MD) and five training days (TD). Study 5 consisted of six training days and one day off. Studies 3 and 4 identified CHO periodisation strategies employed by English Premier League Players such that CHO intake was greater on MD than TD. Additionally, players readily achieve current guidelines for daily protein and fat intakes, although energy and macronutrient intakes are skewed on TD. Study 4 also identified that the GK exceeded average daily EE with EI although he failed to meet current recommendations for meals on MD. In study 5 the player was operating in an energy deficit and he was able to decrease his total body mass in the initial 1-6 weeks post injury, which was attributable to largely fat loss.

In summary, the work undertaken in this thesis has quantified the typical physical loading patterns of professional soccer players according to fixture schedule, starting status and in special populations. Additionally, the quantification of EI and EE (using DLW) also provides the first report of EE in elite soccer players from the English Premier League. When taken together, these data therefore provide a theoretical framework for soccer-specific nutritional guidelines especially in relation to the concept of nutritional (specifically, carbohydrate) periodisation. Further studies are now required to quantify the specific energy and CHO cost of habitual training sessions completed by elite soccer players as well as examining the manipulation of CHO availability on soccer-specific training adaptations.

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Declaration

I declare that the work in this thesis, which I now submit for assessment on the program of study leading to the award of PhD, is entirely my own. Additionally, all attempts have been made to ensure that the work is original, and does not to the best of my knowledge breach any copyright laws, and has not been taken from the work of others, apart from work that has been fully acknowledged within the text of my work.

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CONTENTS

Abstract 2
Acknowledgements 3
Publications and presented abstracts arising from this thesis 6
Table of Contents 8
Contents
List of Abbreviations 12
List of Figures 13
List of Tables 18
Chapter 1 – General Introduction 21
1.1. Background 22
1.2. Aims and Objectives of the thesis 25
Chapter 2 – Literature Review 27
2.1. The physiological demands of soccer match play 28
2.1.1. Activity profiles of soccer match play 28
2.1.2. Positional differences in work rate profiles 28
2.1.3. Aerobic demands of soccer match play 29
2.1.4. Anaerobic demands of soccer match play 31
2.1.5. Summary 32
2.2. The physiological demands of soccer training 31
2.2.1. Objectives of soccer training 31
2.2.2. Quantification of load in soccer 34
2.2.3. Factors influencing training load in soccer 35
2.2.3.1. Coaches influence 35
2.2.3.2. Positional differences 35
2.2.3.3. Starting status 37
2.2.3.4. Weekly schedule 37
2.2.4. Monitoring of training load 38
2.2.4.1. Heart rate 40
2.2.4.2. Rating of perceived exertion 41
2.2.4.3. Global positioning systems 43
2.2.4.4. Semi-automatic camera systems 46
2.2.5. Summary 48
2.3. Nutritional demands of soccer 48
2.3.1. Overview of the metabolic demands of match play 48
2.3.2. Overview of the nutritional recommendations for match play 52
2.3.2.1. Day prior 52
2.3.2.2. Pre-match meal 52
2.3.2.3. During match 53
2.3.2.4. Post-match 54
2.3.3. Overview of the metabolic demands of training 54
2.3.4. Energy demands of soccer players 56
2.3.4.1. Doubly labeled water 56
2.3.4.2. Heart rate 58
2.3.4.3. Accelerometry 61
2.3.5. Assessment of dietary intakes in soccer players 62
2.3.5.1. Diet record (food diary) 63
2.3.4.2. 24-hour recall 64
2.3.4.3. The remote food photographic method 65
2.3.6. Energy intakes in soccer players 66
2.3.7. Carbohydrate periodisation 67
2.4. Summary 68

Chapter 3 – General methodology 71
3.1. Ethical approval and location of testing 72
3.2. Participants 73
3.3. Assessment of body composition 73
3.4. Quantification of training and match load 74
3.5. Measurement of energy expenditure using doubly labeled water 76
3.6. Assessment of total dietary intake 77
3.7. Inter-researcher reliability of the methods 80
Chapter 4 – Quantification of training load during one, two and three game week schedules in professional soccer players from the English Premier League: implications for carbohydrate periodisation 81
4.1. Abstract 82
4.2. Introduction 83
4.3. Methods 85
4.3.1. Participants 85
4.3.2. Study design 85
4.3.3. Quantification of training and match load 86
4.3.4. Statistical analysis 86
4.4. Results 87
4.4.1. Day-to-day variations in training load across one-two and three game weeks 87
4.4.2. One game week schedule 87
4.4.3. Two game week schedule 90
4.4.4. Three game week schedule 93
4.4.5. Accumulative weekly loads 93
4.5. Discussion 96
4.6. Conclusion 101
Chapter 5 – Quantification of seasonal long physical load in soccer players with different starting status from the English Premier League: implications for maintaining squad physical fitness 103
5.1. Abstract 104
5.2. Introduction 105
5.3. Methods 107
5.3.1. Participants 107
5.3.2. Study design 107
5.3.3. Quantification of training and match load 108
5.3.4. Statistical analysis 109
5.4. Results 109
5.4.1. Seasonal long comparison of "total" physical load 109
5.4.2. Seasonal long comparison of total "training" and "match" physical load 110
5.4.3. Seasonal long comparison of "training" and "match" load in high-intensity speed zones 111
5.4.4. Comparison of "total" physical load within specific in-season periods 116
5.4.5. Comparison of "training" and "match" physical load within in-season periods 116
5.5. Discussion 117
5.6. Conclusion 121
Chapter 6 – Energy intake and expenditure of professional soccer players of the English Premier League: evidence of carbohydrate periodisation and 'skewing' of meal distribution 122
6.1. Abstract 123
6.2. Introduction 124

6.3. Methods 125
6.3.1. Participants 125
6.3.2. Study design 125
6.3.3. Quantification of training and match load 126
6.3.4. Measurement of energy expenditure using doubly labeled water 126
6.3.5. Assessment of total dietary intake 126
6.3.6. Statistical analysis 126
6.4. Results 127
6.4.1. Quantification of daily and accumulative weekly load 127
6.4.2. Quantification of daily energy and macronutrient intake 127
6.4.3. Energy and macronutrient intake on training vs. match days 132
6.4.4. Energy and macronutrient distribution across meals on training days 132
6.4.5. Energy and macronutrient intake across meals on match days 136
6.4.6. Carbohydrate intake during training and games 136
6.4.7. Energy expenditure vs. energy intake 136
6.5. Discussion 137
6.6. Conclusion 142
Chapter 7 – Case study: energy intake and expenditure in a Premier league goalkeeper during a typical in-season micro cycle 143
7.1. Abstract 144
7.2. Introduction 145
7.3. Methods 146
7.3.1. Overview of the player 146
7.3.2. Study design 146
7.3.3. Measurement of energy expenditure using doubly labeled water 147
7.3.4. Assessment of total dietary intake 147
7.4. Results 147
7.4.1. Quantification of daily and accumulative weekly load 147
7.4.2. Quantification of daily energy and macronutrient intake 150
7.4.3. Energy and macronutrient distribution across meals on training days 150
7.4.4. Energy and macronutrient intake across meals on match days 154
7.4.5. Carbohydrate intake during training and games 154
7.4.6. Energy expenditure vs. energy intake 154
7.5. Discussion 154
7.6. Conclusion 158
Chapter 8 – Case study: Energy intake and expenditure in a Premier league soccer players during a rehabilitation from ACL injury 159
8.1. Abstract 160
8.2. Introduction 161
8.3. Methods 162
8.3.1. Overview of the player, injury and surgery 162
8.3.2. Study design 163
8.4. Results 163
8.4.1. Quantification of daily energy and macronutrient intake 163
8.4.2. Energy and macronutrient distribution across meals on training days 164
8.4.3. Energy expenditure vs. energy intake 164
8.4.4. Anthropometric developments of the rehabilitation 164

8.5. Discussion 172
8.6. Conclusion 175
Chapter 9 – Synthesis of findings 176
9.1. Synthesis of findings 177
9.2. Achievement of the aims and objectives 177
9.3. General discussion of the findings 179
9.3.1.1. Effects of match schedule 179
9.3.1.2. Effects of starting status 181
9.3.1.3. Effects of positional status 183
9.3.2. Energy requirements of soccer players 186
9.3.2.1. Energy expenditure 186
9.3.2.2. Energy and macronutrient intake 187
9.3.2.3. Energy and macronutrient distribution 188
9.3.2.4. Energy and macronutrient intake in the goalkeeper 190
9.3.2.5. Energy and macronutrient intake in the injured athlete 191
9.3.3. Contemporary training and nutritional guidelines for soccer players 192
9.3.3.1. Training guidelines 192
9.3.3.2. Match day nutrition 193
9.3.3.3. Training day nutrition 193
9.3.3.4. Carbohydrate periodization in soccer 194
9.4. General Discussion 198
9.5. Recommendations for future research 198
Chapter 10 – References 200
Appendices 225

LIST OF ABBREVIATIONS

ACL, Anterior Cruciate Ligament

AMPK, adenosine monophosphate protein

ANOVA, Analysis of Variance

CAM, Central Attacking Midfielder

CD, Central Defender

CDM, Central Defending Midfielder

CF, Centre Forward

CHO, Carbohydrate

CV, Coefficient of Variation

DM, During-Match

EE, Energy Expenditure

EI, Energy Intake

FFA, Free Fatty Acids

FTa, Fast Twitch Type a

FTx, Fast Twitch Type x

GK, Goalkeeper

GPS, Global Positioning Systems

HR, Heart Rate

LBM, Lean Body Mass

PM, Post-Match

PMM, Pre Match Meal

PMRM, Post-Match Recovery Meal

PMS, Pre-Match Snack

RFPM, Remote Food Photographic Method

RPE, Rating of Perceived Exertion

ST, Slow Twitch

$\dot{V}O_{2max}$, maximal oxygen uptake

VO2, Oxygen Consumption

VCO2, Carbon Dioxide Expelling

WD, Wide Defender

WM, Wide Midfielder

LIST OF FIGURES

Chapter 2

Figure 2.1. Blood lactate concentrations from before, during and after a soccer game. Data are means ± SEM (N = 11) as well as individual values (adopted from Krustrup et al., 2006).

Figure 2.2. Relative glycogen content in slow twitch (ST), fast twitch type a (FTa) and fast twitch type x (FTx) fibers as well as all fibers before and immediately after a soccer match (adopted from Krustrup et al., 2006).

Figure 2.3. Plasma FFA concentrations before, during and after a soccer game (adopted from Krustrup et al., 2006).

Figure 2.4. Decline of ^{2}H (deuterium) and ^{18}O in body fluids (urine, plasma or saliva) during a hypothetical doubly labeled water experiment (adopted from Ainslie et al., 2003).

Figure 2.5. The relationship between heart rate and energy expenditure in a healthy male study participant (adopted from Ainslie et al., 2003).

Chapter 3

Figure 3.1. Liverpool Football Club training facilities used for training load data collection in studies 1, 2 and 3.

Figure 3.2. Liverpool Football Club's home stadium used in studies 1, 2 and 3 for collection of physical variables in official games.

Chapter 4

Figure 4.1. Total distance and average speed completed in training sessions and matches duration during the 7-day testing period for different positions and squad average. Figures A and B = one game week, Figures C and D = two game week and Figures E and F = three game week. Bar 1 = Wide Defender, bar 2 = Centre Back, bar 3 = Centre Midfielder, bar 4 = Wide Midfielder, bar 5 = Centre Forward, bar 6 = Squad Average (this sequence of positions is identical in all days and week types). 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 $P<0.05$.

Figure 4.2. Accumulative weekly A) Duration, B) Total distance, C) Standing distance, D) Walking distance, E) Jogging distance, F) Running distance, G) High speed running distance and H) Sprint distance. [a] denotes difference from one game week, [b] denotes difference from two game week, all $P<0.05$.

Figure 4.3. Intensity distribution expressed as percentage of distance completed within each speed zone. Numbers inset represent actual percentage values. [a] denotes difference from one game week, [b] denotes difference from two game week, all $P<0.05$.

Chapter 5

Figure 5.1. Accumulative season long A) duration and B) total distance in both training and matches. Shaded bars = training and open bars = matches. * denotes difference to starters (matches), [#] denotes difference to fringe players (matches), [a] denotes difference to starters (training), $P<0.05$ (Bonferroni corrected).

Figure 5.2. Accumulative season long A) running distance, B) high-speed running distance and C) sprinting distance in both training and matches. Shaded bars = training and open bars = matches. * denotes difference to starters, $P<0.05$ (Bonferroni corrected).

Figure 5.3. Within period accumulative A) duration, B) total distance, C) running distance, D) high-speed running distance and E) sprinting distance in match per se. * denotes difference to starters, # denotes difference to fringe players, P<0.05 (Bonferroni corrected).

Figure 5.4. Within period accumulative A) duration, B) total distance, C) running distance, D) high-speed running distance and E) sprinting distance in training per se. * denotes difference to starters, # denotes difference to fringe players, P<0.05 (Bonferroni corrected).

Chapter 6

Figure 6.1. Daily energy and macronutrient intake expressed absolutely and relative to body mass over the 7-day testing period. Figure A=absolute energy expenditure, Figure B=energy expenditure relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat. White bars=training days and black bars=match days. a denotes difference from day 1, b denotes difference from day 2, c denotes difference from day 3, d denotes difference from day 4, e denotes difference from day 5, f denotes difference from day 6.

Figure 6.2. Energy and macronutrient intakes meal distribution on training days. Figure A=absolute energy expenditure, Figure B=energy expenditure relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat. a denotes difference from breakfast, b denotes difference from morning snack, c denotes difference from lunch, d denotes difference from afternoon snack, e denotes difference from dinner, f denotes difference from evening snack.

Figure 6.3. Energy and macronutrient intake meal distribution on the two match days during the study period. Black bars=match day 1 and white bars=match day 2. a denotes difference from PMM, b denotes difference from PMS, c denotes

difference from DM, d denotes difference from PM, e denotes difference from PMRM. PMM=Pre Match Meal, PMS=Pre-Match Snack, DM=During-Match, PM=Post-Match, PMRM=Post-Match Recovery Meal.

Chapter 7

Figure 7.1. Daily energy and macronutrient intake expressed absolutely and relative to body mass over the 7-day testing period. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat. White bars=training days and black bars=match days.

Figure 7.2. Energy and macronutrient intakes meal distribution on training days. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat.

Figure 7.3. Energy and macronutrient intake meal distribution on the two match days during the study period. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat. Black bars=match day 1 and white bars=match day 2. PMM=Pre Match Meal, PMS=Pre-Match Snack, DM=During-Match, PM=Post-Match, PMRM=Post-Match Recovery Meal.

Figure 7.4. Differences in average daily energy intake vs. average daily energy expenditure and body mass changes from day 0 to day 8. Figure A=energy intake vs. energy expenditure and Figure B=body mass changes.

Chapter 8

Figure 8.1. Daily energy and macronutrient intake expressed absolutely and relative to body mass over the 7-day testing period. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat.

Figure 8.2. Energy and macronutrient intakes meal distribution on training days. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat.

Figure 8.3. Differences in average daily energy intake vs. average daily energy expenditure and body mass changes from day 0 to day 8. Figure A=energy intake vs. energy expenditure and Figure B=body mass changes.

Figure 8.4. Changes in total (A) body mass, (B) lean mass, (C) fat mass and (D) fat percentage. Changes in body mass (E), lean mass (F), fat mass (G) and fat percentage (H) expressed as delta change during the specific period highlighted.

Figure 8.5. Changes in total (A) leg lean mass and (B) leg fat mass. Changes in leg lean mass (C) and leg fat mass (D) expressed as delta change during the specific period highlighted.

Figure 8.6. Changes in total (A) arm lean mass and (B) arm fat mass. Changes in arm lean mass (C) and arm fat mass (D) expressed as delta change during the specific period highlighted.

Figure 8.7. Changes in total (A) trunk lean mass and (B) trunk fat mass. Changes in trunk lean mass (C) and trunk fat mass (D) expressed as delta change during the specific period highlighted.

LIST OF TABLES

Chapter 2

Table 2.1. Distances covered in different positions in soccer players

Table 2.2. Training load data represented across 3 separate 1-week micro cycles during the in-season phase between positions (mean ± SD) (adapted from Malone et al., 2015).

Table 2.3. A typical monthly schedule for a top professional soccer club in the Premier League

Table 2.4. Reported dietary intakes of male soccer players during training (mean daily intake $\pm$ s) (adapted from Burke, 2006).

Chapter 3

Table 3.1. Summary of participant characteristics from all five studies.

Chapter 4

Table 4.1. Overview of the different schedules for each micro-cycle type

Table 4.2. Training and match duration during the 7-day testing period for different positions and squad average

Table 4.3. Distances covered at different speed thresholds (representative of squad average data) during training and matched completed in the 7-day testing period.

Chapter 5

Table 5.1. Total duration (minutes), total distance (km), running distance (km), high-speed running distance (km) and sprinting distance (km) covered across the entire in-season period, as inclusive of both training and matches.

Table 5.2. Total duration (minutes), total distance (km), running distance (km), high-speed running distance (km) and sprinting distance (km) within 5 specific in-season periods

Chapter 6

Table 6.1. Overview of the schedule prior to, during and post testing period

Table 6.2. Training and match load variables (representative of average daily data in bold and individual data from players 1-6) completed in the 7-day testing period and the day following the testing period. Running distance = distance covered between 14.4-19.8 km $\cdot$ h^{-1}, high-speed running distance = distance covered between 19.8-25.2 km $\cdot$ h^{-1} and sprinting distance = distance covered >25.2 km $\cdot$ h^{-1}. Each player's position is shown in brackets. CF=Centre Forward, WD=Wide Defender, WM=Wide Midfielder, CDM=Central Defending Midfielder, CAM= Central Attacking Midfielder and CD=Central Defender.

Table 6.3. Accumulative training and match load variables (representative of average data in bold and individual data from players 1-6) completed in the 7-day testing period and the day following the testing period. Running distance = distance covered between 14.4-19.8 km $\cdot$ h^{-1}, high-speed running distance = distance covered between 19.8-25.2 km $\cdot$ h^{-1} and sprinting distance = distance covered >25.2 km $\cdot$ h^{-1}. Each player's position is shown in brackets. CF=Centre Forward, WD=Wide Defender, WM=Wide Midfielder, CDM=Central Defending Midfielder, CAM= Central Attacking Midfielder and CD=Central Defender.

Table 6.4. Individual differences of average daily energy intake vs. average daily energy expenditure and body mass changes from Day 0 to Day 8. Each player's

position is shown in brackets. CF=Centre Forward, WD=Wide Defender, WM=Wide Midfielder, CDM=Central Defending Midfielder, CAM= Central Attacking Midfielder and CD=Central Defender.

Chapter 7

Table 7.1. An overview of the absolute and accumulative training, match and total physical demands of the player during data collection

Chapter 8

Table 8.1. An overview of a typical days rehabilitation program which the athlete underwent during the assessment week

Table 8.2. An overview of a typical days food consumption during the assessment week (Day 6)

Chapter 9

Table 9.1. Training guidelines which encompass different aspects of soccer training which would suit the nutritional guidelines set out beneath.

Table 9.2. Suggested practical model of the "fuel for the work" required paradigm taken from endurance sports for a one game per week schedule (based on a 80 kg player).

CHAPTER 1

GENERAL INTRODUCTION

1.1. BACKGROUND

Soccer match play is characterised by brief bouts of high-intensity linear and multidirectional activity interspersed with longer recovery periods of lower intensity (Varley & Aughey, 2013). In addition, the requirement for frequent changes in both the speed of movement (e.g., walking, jogging, high-intensity running and sprinting) is also an important factor for soccer performance (Morgans et al., 2014a). Elite players (from one of the top 4 European Leagues) perform 150-250 intense actions per game (Mohr et al., 2003) and complete a high-intensity run approximately every 72 s (Bradley et al., 2009). The demands of match play are further complicated by a number of factors such as psychosocial, tactical and technical elements closely linked to soccer performance. Soccer-specific activity is therefore considered complex and taxes both the anaerobic and aerobic energy systems (Drust et al., 2000; Bradley et al., 2009; Rampinini et al., 2007). A soccer player's fitness levels must therefore be well rounded and suited towards their individual requirement in the team (Stolen et al., 2005).

In order to successfully meet these demands, the physical preparation of elite soccer players has become an indispensable part of the professional game. In contrast to match demands, however, the physical demands of training are not currently well documented and are limited to reports of a single-week exposure (Owen et al., 2014), average values over a 10-week period (Gaudino et al., 2013), group values over a winter fixture schedule (Morgans et al., 2014b) and two examinations into seasonal long load (Malone et al., 2015; Akenhead et al., 2016). It is noteworthy that the overall absolute training loads observed in these studies do not reflect those observed during match play. Nevertheless, there are a multitude of factors that may influence the training load pattern, though the impact of these factors at present is anecdotal and lacks detailed evidence. Further research is required to gain a greater understanding of elite soccer players' absolute physical loads during different situational contexts.

The annual competitive season within soccer is split into three distinct phases: pre-season, in-season and off-season phases (Reilly, 2007). The in-season period comprises the majority of the season with players typically playing 40 competitive matches over a period of 39 weeks. During this period, the management of training loads is traditionally considered in weekly micro-cycles that normally consist of one game per week (i.e. Saturday-to-Saturday schedule), though it is noteworthy that elite soccer players often play two (e.g. Sunday-to-Saturday) or three games (e.g. Sunday-Wednesday-Saturday) in a 7-day micro-cycle. This pattern of loading is largely due to external factors (e.g. television subscription rights) and involvement in numerous competitions (i.e. domestic league/ cup competitions and European competitions) as well as periods of intense fixture schedules such as the winter period (Morgans et al., 2014b). Such scenarios place different challenges upon sports scientists and sports nutritionists as different weekly cycles are likely to alter the absolute load and have subsequent effects on the nutritional requirements for the players. However, no study is yet to quantify the variations in training load that may occur during the weekly micro-cycles that are relevant to those typically undertaken by professional soccer players. Additionally, training load in the weekly micro-cycle is often aimed at providing sufficient recovery from match play (Nedelec et al., 2014), whilst also preventing injury (Dellal et al., 2015; Dupont et al., 2010) and symptoms of over-training (Morgans et al., 2014b), and is usually aimed at those players who are starting each competitive fixture. As such, it could be suggested that it is the participation in match play itself that is the most appropriate stimulus for preparing players for the physical demands of matches (Morgans et al., 2017). This point is especially apparent when considering previous evidence demonstrating positive correlations between individual in-season playing time and aspects of physical performance including sprint performance, muscle strength and counter movement jump height (Silva et al., 2011; Morgans et al., 2017). Nonetheless, the impact of player starting status on overall load during the annual season is not yet known.

Given the potential daily fluctuations in absolute training loads across the micro-cycle, it is likely that EE may vary accordingly and hence, EI could also be adjusted to account for the goals of that particular day. Indeed, the concept of "fuelling for the work required" has recently been suggested as a practical framework for which to apply nutritional periodisation strategies to endurance athletes (Impey et al., 2016). Such strategies are intended to concomitantly promote components of training adaptation (e.g., activation of regulatory cell signaling pathways) but yet, also ensure adequate CHO (and energy) availability to promote competitive performance, reduce injury risk and aid recovery (Burke et al., 2011; Chamari et al., 2012; Burke et al., 2006). This strategy aims to manipulate the CHO (and therefore energy) intakes depending on the load and goals of that particular day. However, despite the growing theoretical rationale for nutritional periodisation strategies, it is difficult to prescribe accurate nutritional guidelines for professional soccer players owing to a lack of study that has provided direct assessments of EE and EI in the modern professional player (Ebine et al., 2002).

In addition to absolute daily energy and macronutrient intake, the "distribution" of such parameters has now been found to be important. Such rationale is well documented for CHO given the relevance of both timing and absolute CHO intake in relation to promoting pre-match loading and post-match muscle glycogen re-synthesis (Ivy et al., 1988a; Ivy et al., 1988b). However, there is also a requirement to quantify daily distribution of protein intakes (Areta et al., 2013; Mamerow et al., 2014). Indeed, these latter authors demonstrated that the timing and even distribution of daily protein doses may have a more influential role in modulating muscle protein synthesis when compared with the absolute dose of protein intake *per se*, an effect that is evident in response to both feeding alone (Mamerow et al., 2014) and post-exercise feeding (Areta et al., 2013). Although such skewed approaches to protein feeding have been previously observed in elite youth UK soccer players (Naughton et al., 2016) and adult Dutch soccer players (Bettonviel et al., 2016), no such study exists examining the daily distribution of macronutrient intake of soccer players of the English Premier League.

The majority of research in soccer is primarily focused around outfield players and there is relatively little research that is specific to the assessing the nutritional requirements of the soccer goalkeeper (GK). Although the GK is often overlooked in research, their playing position is extremely unique and cannot be put into the same category as outfield players. Indeed, whilst match analysis data have verified that GKs display significantly reduced match loads compared with outfield players (Di Salvo et al., 2008; Bradley et al., 2010), researchers have yet to quantify the habitual training loads of professional GKs. This is likely due to the only recent introduction of GK specific Global Positioning Systems (GPS) units for monitoring training load. It is clear that more research is required to quantify the training load and the energy expenditure of the soccer GK in order to prescribe more informed nutritional guidelines.

Throughout the competitive season, it is common for players to sustain both acute and chronic injuries. Injured players are also often overlooked in terms of specific nutritional requirements with many of the daily menus prescribed by club support staff aimed at providing fuel and recovery for competitive match play. However, there has been a recent rise in scientific support to the injured athlete to enable a faster, more efficient return to play. In relation to long-term injuries, the maintenance and in some cases, improvements of body composition and physical capabilities are nowadays essential to a successful return from injury (Milsom et al., 2014). Nonetheless, it is currently difficult to prescribe accurate nutritional guidelines to long-term injured players owing to a lack of understanding of energy requirements during the rehabilitation process.

1.1. AIMS AND OBJECTIVES OF THE THESIS

The primary aim of the present thesis was to quantify the physical loading (both training and match play), EE and EI of elite professional soccer players from the English Premier League. On the basis of characterising the habitual loading patterns and typical EE, a secondary aim was to formulate contemporary nutritional guidelines in accordance with the concept of nutritional periodisation.

This will be achieved by completion of the following objectives:

1. The quantification of training load during one-, two- and three-game week schedules in professional soccer players from the English Premier League. This objective will be achieved through completion of Study 1 (Chapter 4).

2. The quantification of seasonal long physical load in soccer players with different starting status from the English Premier League. This objective will be achieved through completion of Study 2 (Chapter 5).

3. The quantification of training load, EE and EI (including daily macronutrient distribution) in professional soccer players of the English Premier League during a typical in-season micro-cycle. This objective will be achieved through completion of Study 3 (Chapter 6)

4. The quantification of physical load, EE and EI (including daily macronutrient distribution) in a professional soccer GK from the English Premier League during a typical in-season micro-cycle. This objective will be achieved through completion of Study 4 (Chapter 7).

5. The quantification of EE and EI in a professional soccer player from the English Premier League during rehabilitation from ACL injury. This objective will be achieved through the completion of Study 5 (Chapter 8).

CHAPTER 2

LITERATURE REVIEW

2.1. THE PHYSIOLOGICAL DEMANDS OF SOCCER MATCH PLAY

2.1.1. ACTIVITY PROFILES OF SOCCER MATCH PLAY

Soccer match play has been characterised by its sporadic nature whereby multidirectional unpredictable physical actions are integrated with an array of technical skills (Bradley et al., 2009; Wallace & Norton, 2014; Bush et al., 2015b). The physical demands of soccer match play have been studied extensively for over four decades (Reilly & Thomas, 1976; Di Salvo et al., 2006; Di Salvo et al., 2009; Russell et al., 2016). The typical total distance covered by a top-class outfield player during a soccer match is around 10-13 km (Dellal et al., 2011; Di Salvo et al., 2007). Relative to the overall distance covered by players, ~80-90% of it is covered in low to moderate intensity activity (speeds <19.8 km $\cdot$ h^{-1}), with ~7-12% covered at high-intensity (speeds >19.8 km $\cdot$ h^{-1}) and 1-4% whilst sprinting (speeds >25.2 km $\cdot$ h^{-1}) (Bradley et al., 2009; Di Salvo et al., 2010; Rienzi et al., 2000). Furthermore, the demands in the English Premier League are evolving over time with an increase in distance covered at high-intensity being observed between 2007-2014 (Barnes et al., 2014). In addition to running match demands, each player performs around 1000 – 1400 short activities changing every 4 – 6 seconds during a match (Mohr et al., 2003). These include around 30 – 40 sprints (Bangsbo et al., 2006), more than 700 turns (Bloomfield et al., 2007) and 30 – 40 tackles and jumps (Bangsbo et al., 2006). Other actions including kicking, dribbling and tackling are also endured although these are difficult to quantify specifically for each match (Bangsbo, 1994).

2.1.2. POSITIONAL DIFFERENCES IN ACTIVITY PROFILES

Understanding the different physiological load imposed on players with regards to their positional role in the team can further enhance soccer specific training (Di Salvo et al., 2007). A number of studies have identified positional differences in match data, such as central midfielders covering the highest distance during a match and central defenders covering the least (excluding goalkeepers) (see Table 2.1.). The greater distance covered by central midfield players is suggested to be a product of both higher levels of fitness associated with such players and the role which they play in the team (linking between defence and attack), a role which evidently requires more sustained running (Bangsbo, 1994; Bangsbo & Michalsik, 2002; Bloomfield et al., 2007; Reilly & Thomas, 1976). Wide midfielders and wide defenders have been reported to cover greater distances in high-intensity running (>14.4 km · h^{-1}), whilst both wide midfielders and full backs cover greater distances sprinting (>25.2 km · h^{-1}) compared to other outfield positions (Bradley et al., 2009). The greater high-intensity running distance covered by wide midfielders is suggested to be a product of their tactical role in the team and due to their high-intensity runs being the longest in distance (Bradley et al., 2009). The greater sprint distance could be of a similar tactical role in the team for both wide midfielders and full backs with a greater amount of long runs in behind the opposition defence and recovery runs to stop counter attacks from the opposition. Soccer is therefore a complex sport with clear evidence of position specific high-intensity demands.

2.1.3. AEROBIC DEMANDS OF SOCCER MATCH PLAY

Soccer match play typically consists of large amounts of moderate to low intensity activity (Di Salvo et al., 2007; Rienzi et al., 2000). Although it is difficult to directly measure, analysis into the physical performance of match play provides evidence for players' aerobic energy systems being highly taxed during match play (Stolen et al., 2005). It could, however, be supported by research reporting mean and peak heart rates of around 85 and 98% of maximal, respectively (Krustrup et al., 2005; Mohr et al., 2004; Suarez-Arrones et al., 2015; Torreño et al., 2016). These heart rate values correspond to an average exercise intensity of approximately 70% of maximal oxygen uptake ($\dot{V}O_{2max}$) (Bangsbo et al., 2006) and give further evidence that the aerobic energy system is frequently stressed during match play.

Table 2.1. Total distances covered during matches for soccer players in different positions.

Reference	League/Competition Level (sex)	No.	Total Distance (m)	Fullback (m)	Central defender (m)	Midfielder (m)	Forward (m)
Anderssen *et al.,* (2007)	International Swedish/Danish (F)	11	10000				
	Elite Swedish/Danish (F)	11	9700				
Barros *et al.,* (2007)	Brazilian 1st Division (M)	55	10012	10642	9029	10537*	9612
Burgess *et al.,* (2006)	Professional Australians (M)	36	10100	8800#		10100	9900
Di Salvo *et al.,* (2007)	Professional European Leagues (M)	300	11393	11410	10627	12009*	11254
Di Salvo *et al.,* (2007)	Champions League Matches (M)	791	11010		10020	11570	
Fernandes *et al.,* (2007)	Portuguese first division (M)	3	12793	14199#		12958	11224
Helgerud *et al.,* (2001)	Elite Norwegian Juniors (M)	9	10335				
Hewitt *et al.,* (2007)	International Australian (F)	6	9140	9010#		9640	8510
Holmes (2002)	Elite English (F)	5	12400				
Krustrup *et al.,* (2005)	Elite Danish (F)	14	10300				
Impellizzeri *et al.,* (2006)	Italian junior professionals (M)	29	9890				
Miyagi *et al.,* (1999)	Japanese professionals (M)	1	10460				
Mohr *et al.,* (2003)	Italian professionals (M)	18	10860	10980	9740	11000	10480
Odetoyinbo *et al.,* (2007)	English professionals (M)		10659				
Rampinini *et al.,* (2007)	European professionals (M)	18	10864				
Randers *et al.,* (2007)	Danish Premier League (M)	23	10800				
	Swedish Premier League (M)	23	10150				
Rienzi *et al.,* (2000)	South American professionals (M)	17	8638				
	English professionals (M)	6	10104				
Scott and Drust (2007)	International English (F)	30	11979	12636	11099	12971	11804
Strudwick and Reilly (2001)	English professionals (M)	24	11264	11433	10650	12075	
Thatcher and Batterham (2004)	English professionals (M)	12	10274				
	U/19 professionals (M)	12	9741				
Zubillaga *et al.,* (2007)	Champions League matches	18	10461				

* Combined results for central and external midfield players; # Results did not distinguish between fullbacks and central defenders

2.1.4. ANAEROBIC DEMANDS OF SOCCER MATCH PLAY

Although aerobic metabolism dominates energy production during a soccer match, the most decisive actions are highly dependent anaerobic metabolism (Cometti et al., 2001; Faude et al., 2012; Wragg et al., 2000). For example, straight sprints were most frequent action in goal situations (Faude et al., 2012). Also, performance in short-sprinting actions can distinguish between playing level (Cometti et al., 2001). Match analysis data demonstrates that elite soccer players perform 150-250 brief intense actions during a game (Mohr et al., 2003), indicating that the rate of anaerobic energy turnover is high at certain times. Additionally, there is evidence supporting the anaerobic metabolism demands in soccer match play from more direct methods such as analysis of muscle and blood metabolites. Intense actions during a game would lead to a high rate of creatine phosphate breakdown, which to an extent is resynthesised in the subsequent low intensity exercise periods (Bangsbo, 1994). In parts of a match, concentrations of creatine phosphate in the muscle have also been reported to decline below 30% of resting values following intense exercise periods when recovery periods are short in duration (Krustrup et al., 2006). Additionally, previous research has reported mean blood lactate values of up to 10 mmol.l^{-1} during soccer matches (Bangsbo, 1994; Krustrup et al., 2006; see Figure 2.1.). This evidence, along with the data from match analysis, suggests a significant contribution from anaerobic metabolism during match play.

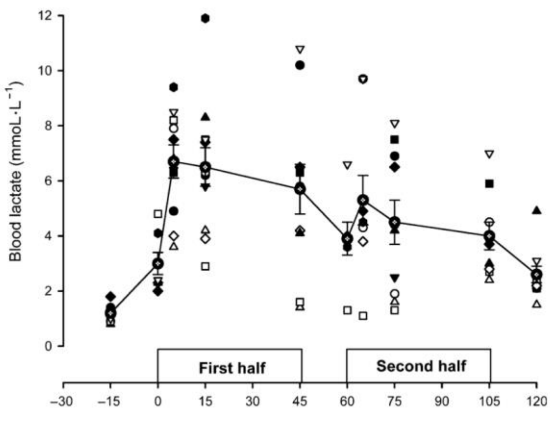


Figure 2.1. Blood lactate concentrations from before, during and after a soccer game. Data are means ± SEM (*N* = 11) as well as individual values (adopted from Krustrup et al., 2006).

2.1.5. SUMMARY

The match demands of soccer have been studied extensively. It is now understood that match play consists of high intensity anaerobic efforts superimposed on a base of aerobic activity. However, the demands can be more complex given the players positional and tactical role in the team. It is therefore essential to train the aforementioned systems in accordance to the players match demands in order to improve or maintain soccer specific match fitness.

2.2. THE PHYSIOLOGICAL DEMANDS OF SOCCER TRAINING

2.2.1. OBJECTIVES OF SOCCER TRAINING

The objective of the training process in soccer is to administer a correct frequency, volume, and intensity of training to deliver the appropriate psychological and physiological stimuli to achieve adaptations which will improve individual and team performance (Akenhead et al., 2016). As previously discussed, soccer match play has contributions from both aerobic and anaerobic energy systems. Training programs for players will therefore need to include activities and exercise prescriptions that stress these systems. Players also need to possess muscles that are both strong and flexible as these attributes are important for the successful completion of technical actions (e.g., passing, shooting, *etc.*), which ultimately determine the outcome of the match (Morgans et al., 2014a). Fortunately, unlike matches, soccer training can consist of different drills that the coaches can prescribe in order to fulfill different physical aspects of training (Bangsbo et al., 2006). These drills should include activities and exercises that stress both of these systems (Morgans et al., 2014a). In addition, the prescription of such training load is heavily influenced by competition frequency, with in-season micro-cycles of typically 3-7 days in duration. Therefore, following the preseason period players are often required to establish a “multiple peaking” periodisation model to enable a high performance during matches throughout the season (Mujika, 2010; Pyne et al., 2009). This then complicates the training load prescription with respect to the fixture schedule to enable enough recovery from the last fixture and enable freshness leading into the next. As such, specific attention should be made to the designing of training sessions in different weekly micro-cycles. In addition to the match frequency, match play is often deemed to be the highest load during the weekly micro-cycle and will potentially leave non-starting players not experiencing match load, which can potentially lead to a decrease in soccer-specific fitness levels (Silva et al., 2011). More information is therefore required to identify the different contextual factors that affect training load.

Soccer training can be described in terms of its process (the nature of the exercise) or its outcome (anatomical, physiological, biochemical, and functional adaptations) (Impellizzeri et al., 2004; Impellizzeri et al., 2005; Viru & Viru, 2000). The training process is prescribed by the teams coaching staff (i.e., conditioning drills, technical drills, or small sided games) and it has now become common to examine these processes using a magnitude of devices to see if has met the desired outcomes. In simple terms, the training process is most commonly referred to as the external training load. However, the different training processes prescribed will often produce different physical outputs between players as they will cover different distances, distances in different speed zones and accelerations *etc.* that will ultimately lead to different external training load. For example, a central midfielder is likely to cover more distance than a central defender in a small-sided game (e.g. 5v5 for 4x4minutes) as they typically possess greater aerobic fitness levels due to the role they play in the team. Therefore, monitoring of this external load in training sessions is key to understanding the true external load. The training outcome is a consequence of this external training load and the associated level of physiological stress that it imposes on any given individual player (which is referred to as the internal training load) (Viru & Viru, 2000). To optimise athletic performance, physical training programs should be prescribed to suit each athlete’s individual characteristics (Alexiou & Coutts, 2008). However, soccer training is most commonly performed as a team and although different external loads can be experienced, it is important to monitor the internal training load as it varies between individuals in the group to how they have responded to a given stimulus and it is this component of physical training that produces the stimulus for adaptations (Booth & Thomason, 1991; Manzi et al., 2010; Viru & Viru, 2000).

When taken together, it is clearly important to assess both the external and internal training load in order to assess the relationship between them and individual player responses (Scott et al., 2013).

2.2.2. QUANTIFICATION OF TRAINING LOAD IN SOCCER

In order to successfully meet match demands, the physical preparation of elite players has become an indispensable part of the professional game, with high fitness levels required to cope with the ever-increasing demands of match play (Iaia et al., 2009; Barnes et al., 2014). Nonetheless, despite nearly four decades of research examining the physical demands of soccer match play (Reilly & Thomas, 1976), the quantification of actual daily training loads completed by elite professional soccer players are not currently well known. There are a multitude of reasons for this lack of research but they are potentially due to the only recent rise in the use of GPS in elite soccer training sessions. Additionally, there is a large confidentiality issue regarding the training of elite players with club staff often refusing to "give away" training data, as they perceive it as their 'secret' information.

Of the current available research literature on training load quantification in soccer, the body of work has focused on either individual training drills or short periods of a training program. Most research has been conducted into small-sided games and their outcomes under varying conditions (Hill-Haas et al., 2011). However, research looking at the absolute external training load for professional soccer players has now started to emerge. For example, studies now exist examining the training load during a single week (Owen et al., 2014), a 10-week period (Guadino et al., 2013), the periodisation strategies adopted by an elite club (Malone et al., 2015) and more recently, average values from training over a season when one game was played per week (Akenhead et al., 2016). Although training load studies are now starting to be undertaken, it is important to understand the contextual factors, which can influence training load as each one can alter both the absolute training stimulus and influence the subsequent nutritional requirements.

2.2.3. FACTORS INFLUENCING TRAINING LOAD

2.2.3.1. COACHES INFLUENCE

Ultimately, in professional soccer, the head coach is responsible for the 'on pitch' training program and it is their decision what to do in order to match their needs. For example, training load in-season can be as high as 11.8 km total distance (Owen et al., 2014), whereas Akenhead et al. (2016) observed that the maximum load on one of the high load days in season reached 6.5 km total distance. In addition, the role of the coach has shown different micro-cycle structures in the organization of training sessions that could potentially influence adaptations and overall training load during the week (Malone et al., 2015; Akenhead et al., 2016). Further to the planning and delivery of training sessions, coaches often have different styles in the way they work and different amounts of verbal encouragement can be given which have been found to increase the intensity of small sided games (Hoff et al., 2002) and subsequent physiological responses (Rampinini et al., 2007). In addition to the training load, coaches can influence match load in regards to the formation that they play on match day (Tierney et al., 2016) and playing style (Bradley et al., 2013). This gives sufficient evidence of the role of the coach on the training load undertaken by elite soccer players.

2.2.3.2. POSITIONAL DIFFERENCES

There are significant positional differences in physical load observed in soccer match play (Bradley et al., 2009; Bloomfield et al., 2007; Di Salvo et al., 2007; Mohr et al., 2003). With regards to soccer training, soccer training is often prescribed as an entire team; it is often dependent on the type of drill prescribed whether positional differences are observed (Morgans et al., 2014b). For example, small-sided games that are played in large spaces (e.g. 75x60m) with large numbers (e.g. 11v11) will encompass game like situations and allow actions to be performed in their positions and similar to what would be performed in match play. However, small-sided games that are played in small spaces (e.g. 35x20m) with small player numbers (e.g. 4v4) can partially remove positional differences due to more intensive and less organizational requirements for these games.

Training load research that provides analysis into positional differences has been examined in teams from the English Premier League (Malone et al., 2015; Akenhead et al., 2016). These studies found that central midfield players cover a greater amount of distance in training over the course of a season. Additionally, wide midfield players covered greater distance in high-intensity speed zones than central defenders (see Table 2.2.) However, the role of the coach can also have an effect on training load as the manipulation of pitch sizes in small-sided games can bring further match like scenarios and therefore, obvious positional differences are likely to occur (Dellal et al., 2012).

Table 2.2. Training load data represented across 3 separate 1-week micro cycles during the in-season phase between positions (mean ± SD) (adopted from Malone et al., 2015).

Period, position	Total distance (m)	Average speed (m/min)	High-speed distance (m)
Week 7			
CD	6066 ± 1885	78 ± 10	190 ± 202
WD	6024 ± 1990	84 ± 8	224 ± 223
CM	6426 ± 1804#	85 ± 10$	234 ± 225
WM	6265 ± 1936	80 ± 6	293 ± 262∆
ST	5780 ± 1823	74 ± 5	303 ± 258
Overall	**6182 ± 1841**	**81 ± 9**	**243 ± 229**
Week 24			
CD	5719 ± 1066	82 ± 5	169 ± 186
WD	6274 ± 1201	88 ± 4	237 ± 195
CM	6515 ± 1065#	89 ± 6$	271 ± 283
WM	6148 ± 1105	83 ± 4	217 ± 169∆
ST	5602 ± 1111	80 ± 5	244 ± 224
Overall	**6105 ± 1121**	**85 ± 6**	**225 ± 213**
Week 39			
CD	4203 ± 1514	75 ± 5	75 ± 80
WD	4185 ± 1403	81 ± 7	137 ± 92
CM	4911 ± 1669#	82 ± 5$	161 ± 121
WM	4616 ± 1634	77 ± 5	179 ± 103∆
ST	4866 ± 2102	76 ± 9	184 ± 105
Overall	**4714 ± 1581**	**79 ± 7**	**146 ± 104**

Abbreviations: CD, central defenders; WD, wide defenders; CM, central midfielders; WM, wide midfielders; ST, strikers. #CM significant difference vs CD and ST; ∆WM significance vs. CD; $CM significant difference vs. ST

2.2.3.3. STARTING STATUS

A player's starting status often provides a difficult situation for sports scientists with regards to replicating match load for non-starting players to enable maintenance of fitness levels. Evidence of the methodological manipulation of training load in the recovery from and in the build up to a competitive fixture illustrate the importance of the match to the overall planning and preparation strategies used within soccer (Malone et al., 2015). It is evident that match load values are significantly greater than training load values. This is the case for parameters such as total distance (e.g. < 7 km v ~10-13 km) (Bangsbo et al., 2006), high-speed running distance (e.g. < 300 m v > 900 m) and sprinting distance (e.g. < 150 m v > 200 m) (Di Salvo et al., 2010) and therefore creates a difficult situation for the sports scientist with regards to maintaining players fitness levels who do not start matches. As such, it could also be suggested that it is the participation in match play itself that is the most appropriate stimulus for preparing players for the physical demands of match play. This point is especially relevant considering previous evidence demonstrating significant positive correlations between individual in season playing time and aspects of physical performance including sprint performance and muscle strength (Silva et al., 2011). More recently, Morgans et al. (2017) demonstrated evidence of improved counter movement jump height being proportional to the amount of high-intensity distance covered in match play itself. Therefore, it is evident that match play is a potent stimulus in the development of physical qualities associated with soccer. In order to examine differences in load between players with different starting status it is clear further information is required to inform practice.

2.2.3.4. WEEKLY SCHEDULE

In addition to the aforementioned variables, another factor that can influence the training load is the weekly fixture schedule (see Table 2.3.). In soccer, training loads are often managed in weekly micro-cycles depending on how many training days are available between matches (Malone et al., 2015). For example, Akenhead et al. (2016) reported that 27 weeks of a 39-week season contained one competitive match, 8 weeks featured two games, and 4 weeks featured 0 games, which were most likely to be periods which allowed time for International fixtures. However, in this study the team was only competing for domestic honors and their exposure to two games per week was limited when compared with a team competing for domestic and European honors. Additionally, there are periods where players are expected to perform in competitive match play every 2-3 days such as the winter period (Morgans et al., 2014b) and times when players are competing in both domestic and European honors (Djaoui et al., 2013). Such scenarios are likely to influence training load between matches as emphasis is placed upon regeneration and recovery of the starting players and preparation for the subsequent game (Nedelec et al., 2014). Further information is now required to quantify training load in altered weekly scenarios.

Table 2.3. A typical monthly schedule for a top professional soccer club in the Premier League

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
						1 League Fixture
2 Recovery am	**3** Match Day -1	**4** EFL Cup Fixture	**5** Recovery am	**6** Match Day -1	**7** League Fixture	**8** Recovery am
9 Match Day -1	**10** CL Fixture	**11** Off	**12** Match Day -2	**13** Match Day -1	**14** League Fixture	**15** Off
16 Match Day -2	**17** Match Day -1	**18** CL Fixture	**19** Off	**20** Match Day -2	**21** Match Day -1	**22** League Fixture
23 Off	**24** Off	**25** Match Day - 4	**26** Match Day -3	**27** Match Day -2	**28** Match Day -1	**29** League Fixture
30 Off	**31** Match Day +2	**1** Match Day - 3	**2** Match Day -2	**3** Match Day -1	**4** FA Cup Fixture	**6** Off

EFL = English Football League, FA= Football Association, CL=Champions League

2.2.4. MONITORING OF TRAINING LOAD IN SOCCER

In order to optimise the training process and the subsequent internal response, the training load prescribed must be individualised to suit the needs of each individual player (Alexiou & Coutts, 2008). Whilst too much and too little training load may lead to accumulated fatigue (non-functional overreaching or overtraining) and detraining, respectively, an appropriate training dose at the individual level may allow optimal improvements in fitness and performance (Bouchard & Rankinen, 2001: Hautala et al., 2006, Borresen & Lambert, 2009; Manzi et al., 2009, 2013; Castagna et al., 2011). Additionally, the inappropriate training load may lead to increased injury rates (Gabbett, 2016), increased susceptibility to infection (Morgans et al., 2014b) and reduced subjective recovery measures (Brink et al., 2012).

To examine whether soccer players are meeting, or indeed exceeding, training load requirements, it is vital to monitor their individual training load (Scott et al., 2013). There are a variety of different methods used to quantify training loads undertaken by athletes (Borresen & Lambert, 2009). The most common methods currently used to quantify training load in soccer involve analyzing players' heart rate and rating of perceived exertion (RPE) (Alexiou & Coutts, 2008). However, recent advances in technology have now seen the increase in use of GPS in soccer training (Cummins et al., 2013) and now (due to a recent FIFA and UEFA rule changing) competitive matches. It is now common practice for elite soccer clubs to use GPS and heart rate monitors to receive comprehensive and real-time analysis of on-field player performance during competition and training (Cummins et al., 2013). Additionally, during matches clubs often use semi-automatic cameras in order to track players movements during competitive games. This was developed due to the previous restriction of wearing any monitoring device during competitive matches and has been used in many leagues around the world. Although there are many methods to quantify training and match load, in professional football many of the methods are used collectively in order to give an overall perspective of physical load. Each method has their own advantages and disadvantages and will now been discussed individually.

2.2.4.1. HEART RATE

The use of HR monitors to quantify players' internal responses is now commonplace in professional soccer. Nowadays, HR monitors are a noninvasive method that are used to quantify the cardiovascular strain placed on an individual to a given training load (Drust et al., 2007). This can enable practitioners to differentiate the internal response of an individual to the external load that was provided. For example, different pitch sizes and players numbers in small-sided games can elicit different HR responses on individuals and a group of players (Owen et al., 2011; Hill-Haas et al., 2011). In addition, simple technical/ tactical conditions can affect the internal response (Sassi et al., 2005). Therefore, the integration of simultaneous HR monitoring and the use of GPS or multiple camera systems can provide a precise profile of each player (Drust et al., 2007). This combination could improve the link between the external demands of the session and different drills and the cardiovascular exertion in responses.

Originally, HR was measured via continuous electrocardiogram (ECG) recording, which were transmitted by short-range radio telemetry. However, this was limited during soccer like activities as the connection of the electrodes to the skin surface was compromised (Ali & Farrally, 1991). Since then, there has been a development in radio telemetry technology, which has allowed for the creation of 'team systems' such as the Polar Team 2 and are now commercially available to soccer teams. This has allowed real-time HR monitoring with the possibility to intervene if a player is receiving an undesired training response rather than intervening after the session has finished and the data has been downloaded. In addition to these technological advances, nowadays soccer teams use HR in conjunction with GPS systems and are interlinked in the software. In soccer, it is common to use this method during training sessions although difficulty arises when players are to perform in match play and no GPS or HR is worn. Until recently, a FIFA ruling meant that players were not permitted to wear any integrated technology during match play although implementation of such monitoring strategies in elite teams is still scarce. Therefore, the complete cardiovascular stress of the weekly micro-cycle cannot be monitored.

Although the use of HR monitoring is practical, like many methods to quantify training, it is not without its limitations and many factors influence the relationship between workload and HR. For example, HR monitors are used in soccer based on the principle that there is a linear relationship between HR and $\dot{V}O_{2max}$ over a range of steady state submaximal workloads (Astrand & Rodahl, 1986). However, caution should be taken when interpreting the linear HR-$\dot{V}O_{2max}$ relationship. This relationship is based on a continuous treadmill running test, and this linearity does not necessarily apply during soccer due to its intermittent nature (Hoff et al., 2002; Wicks et al., 2011). Moreover, the day-to-day variation in HR is ~6 bpm (Lambert et al., 1998). Additionally, external factors such as environmental conditions, hormonal variations (i.e. adrenaline), diurnal changes, fatigue, hydration status, altitude, (Achten & Jeukendrup, 2003) and medication can alter the HR responses of players and are often not taken into account when analyzed. Perhaps the way to overcome such limitations is to provide a global approach to training load analysis and use a combination of methods. This can allow a more precise profile of each individual player according to their playing position. Such monitoring tools will now be discussed separately below.

2.2.4.2. RATING OF PERCEIVED EXERTION

A rating of perceived exertion (RPE) is based on the understanding that athletes can inherently monitor an individual's internal response to an external stimulus and it is one of the most commonly used methods to quantify the intensity and load of training sessions in soccer (Coutts et al., 2009; Borresen & Lambert, 2009). Originally, the RPE scale was developed by Borg (1970) but since then, there have been many adaptations that can allow an increased understanding of training. For example, Foster et al. (2001) proposed an alternative method that utilised Borg's CR-10 RPE scale (Borg 1982) to simplify the quantification of training load. Although this method was originally developed for endurance athletes, research has shown that it has good levels agreement to HR methods when quantifying internal training response in soccer players (Impellizzeri et al., 2004, Alexiou & Coutts, 2008). Moving forward, new methods stressed for the need of more information from the RPE score. Therefore, the Foster et al., (2001) CR-10 scale score can be multiplied by the session duration in order to account for an increased volume and/ or intensity to give a 'session load' score, to which it has been validated in soccer (Impellizzeri et al., 2004). Additionally, RPE does not require particular expensive equipment or training and can therefore be very useful and practical for sports scientists and coaches to monitor and control load. However, players and practitioners must follow correct procedures when collecting data in order for the data to be true and effective. For example, practitioners must familiarise players with the scales prior to use and the data should be collected individually to prevent other individuals influencing the rating given (Burgess & Drust, 2012).

Although there are many advantages of measuring RPE post training sessions to quantify internal training load, it is not without its limitations. Firstly, the complex interaction of many factors which contribute to the personal perception of physical effort, including hormone and substrate concentrations or personality traits may limit the use of RPE in accurately quantifying exercise intensity (Borresen & Lambert, 2009). Additionally, RPE requires the athlete's own perception of training stress, which can include their psychological stress. Therefore, it is possible that players could perceive the same physiological stimulus differently as a consequence of their individual psychological state (Morgan, 1973). For example, if a player was on different team during a small-sided game in the training session that he felt didn't reflect their current form (i.e. the next games perceived starting team) this could leave them in a negative mood that results in a change of the players true RPE score for the given session. Therefore, sports scientists and coaches are left to rely on the individual player to provide an accurate RPE of the session. Additionally, it is the responsibility of the sports scientist and/ or coach who is taking the score to provide familiarisation and allow for individual assessments to take place. Although RPE as a subjective measure may not be as accurate as objective measures such as HR, the combined use with the addition of GPS may provide a more complete picture and allow coaches to make more informed decisions.

2.2.4.3. GLOBAL POSITIONING SYSTEMS

The development of GPS in 1990 has enabled the collection of real-time data on human locomotion to examine sport performance in a more convenient, efficient, and precise manner (Dellaserra et al., 2014). Originally, GPS was developed for military purposes and first used for athlete tracking in 1997 (Schutz & Chambaz, 1997). Global positioning systems consist of 27 satellites equipped with atomic clocks that orbit around the earth. These satellites continually send information to GPS receivers and, using these signals, the receivers calculate the distance to the satellite (Larsson et al., 2003). This is achieved by comparing the difference in time between the satellites atomic clock encoded in the signal to the internal clock of the receiver (Scott et al., 2016). A connection to a minimum of four satellites is required to determine the position of the GPS receiver (Larsson et al., 2003). With commercial GPS receivers, the speed the device is moving at is calculated using Doppler shift (Scott et al., 2016). This is attained by examining frequency of the satellite signal and is subject to change because of the movement of the receiver (Larsson et al., 2003). Such commercial GPS systems are now commonly used in team sports such as soccer to provide sports scientists and coaches with comprehensive real-time analysis of on-field player performance during competition or training.

Global positioning systems are classified by the rate at which they sample per second. When they were first used in human locomotion and indeed with elite soccer clubs, commercial devices had a sample rate of 1Hz (1 sample per second). However, due to rapid advancements in the technology, sampling rates have subsequently improved where now 10 and 15Hz units exist. Alongside these developments, the development and subsequent acceptance of micro-technology in sport has led to the integration of other micro inertial sensors within GPS devices, such as tri-axial accelerometers, magnetometers and gyroscopes; collectively termed as micro electrical mechanical system (MEMS) devices (Malone et al., 2017a). The tri-axial accelerometer measures a composite vector magnitude (expressed as a G-force) by recording the sum of accelerations measured in three axes (*X, Y, and Z* planes) (Waldron et al., 2011). Typically, in commercial GPS units the accelerometers have a sampling frequency of 100Hz and therefore offer a higher sampling rate compared to devices without (Boyd et al., 2011). Therefore, the integration of GPS with a tri-axial accelerometer enables the capture of information on work rate patterns and more comprehensive information on physical loading. This has led to the widespread use in elite soccer clubs during training and more recently (due to a change in FIFA ruling) a growing use during competitive match play.

In comparison to other tracking techniques, GPS is time efficient and provides real-time feedback, allowing greater practicality in team sports (Scott et al., 2016). They have the ability to objectively quantify the external training load of individual athletes during training and matches. Currently, practitioners can use a wide range of variables in order to quantify the frequency, volume, and density of the external training load components. Manufacturers provide these variables but practitioners mainly use variables such as total distance covered, the distance covered in different velocity ranges and/or the number of times they have executed a run at a speed in each velocity range. An understanding of the different movement demands of soccer training can allow a greater understanding of the total physical load (Akenhead et al., 2016) and give potential indications to energy system utilisation. To further enhance the comprehensive understanding of training load, the development of tri-axial accelerometers in GPS devices has allowed for the quantification of different metabolic demanding activities in all three planes of movement that are not taken into account by the analysis of movement profiles alone (Barrett et al., 2014). These measures are based on the instantaneous rate of change in acceleration in each of the three vectors (X, Y and Z axis). Using the accelerometers a vector-magnitude algorithm, which is termed differently by each GPS manufacturer, the variable can be produced. The most commonly used metric in the research literature being PlayerLoad (Boyd et al., 2014; Barrett et al., 2014; Akenhead et al., 2016). Although such measures of accelerometer load have demonstrated acceptable levels of inter- and intra-unit reliability (Boyd et al., 2011; Kelly et al., 2015), it is still not common place for players to use GPS devices during competitive match play at the elite level.

Despite the advantages of using GPS systems to analyze and interpret external training and match load, practitioners must understand the limitations around validity and reliability of GPS devices in order to accurately interpret data. The first attempt to validate a commercially available GPS device for the measurement of human locomotion was published in 1997 (Schutz & Chambaz, 1997). Here they used one participant who undertook a number of different trials at different velocities, comparing GPS data to a Swiss chronometer. Although the results seemed promising for GPS use (r = .99 and 5% CV), the methodology was not considered gold standard for measuring GPS velocities. Since then, there has been an abundance of literature examining the validity and reliability of GPS for the measurement of movement in and more specifically, soccer specific movements. In addition, when GPS units are increased in velocity and players move in a multidirectional motion there becomes a decreased accuracy of measurement. For example, during initial testing of the 1-5Hz units, the validity and reliability of short distance linear running were found to be poor. Moreover, Rampinini et al. (2015) found that 10Hz GPS devices had good accuracy for total distance and high speed running (CV = 1.9% and CV = 4.7%, respectively). However, accuracy became poor during very high-speed running (CV = 10.5%) (Rampinini et al., 2015). Unlike, 1-5Hz GPS devices, 10Hz were found to have no significant difference to the criterion method of a tape measure in a team sport simulated circuit consisting of change of direction activities (Johnston et al., 2014). In addition, the quality of satellite coverage can also give limitations when using the GPS unit and this has to be taken into account upon analysis. Despite such limitations, GPS is now one of the most common monitoring tools used in soccer training as it can provide extensive feedback on the external training load in real-time. However, practitioners must be aware that they should individually quantify their GPS systems degree of error and consider this in any of the decision-making processes. In order to limit the degree of error when using GPS devices, practitioners are advised to follow individual manufacturers guidelines in order to get the 'best' data. For example, conducting the activity in an open space instead of covered area such as soccer stadiums will allow an increased number and enhanced signals to the surrounding satellites. Additionally, manufacturers often advise to turn devices on 30 minutes prior to activity in order to allow satellite lock on.

Until recently, the concomitant use of GPS and semi-automatic motion analysis software such as ProZone® has been widely used in training sessions and matches, respectively. This was partly due to the FIFA ruling that did not permit players to wear tracking devices in competition. This rule has now been overturned but tracking devices such as GPS are still rarely used at the elite level. Therefore, teams would typically employ a semi-automatic camera system such as ProZone® and Amisco to quantify match movement demands and use GPS to quantify training demands. However, the simultaneous use of GPS and semi-automatic camera systems has obvious implications. GPS (1Hz and 5Hz devices) has been shown to under-report high intensity running, low intensity running and total distance compared to the Amisco system (Randers et al., 2010). Additionally, Harley et al. (2011) reported that both sprint distance and high-intensity running distances were underestimated in 5Hz GPS devices compared to the ProZone® system. This study concluded that sprint performances were ~40% different between systems. Also, in 10Hz devices, high speed running and sprinting were suggested to be underestimated compared to ProZone® systems by 10-15% and 15-20%, respectively (Milsom et al., Unpublished Data). In an attempt to overcome such issues between systems, Buchheit et al. (2014) provided equations for data in order to make systems more interchangeable in tracking longitudinal load, designing training programs and drills. Nevertheless, this is the approach to monitoring that is commonly employed by sports scientists in the elite soccer environment and is currently a difficult methodological issue to overcome.

2.2.4.4. SEMI-AUTOMATIC CAMERA SYSTEMS

The monitoring of players' activity profiles during competition was originally achieved during real-time analysis from one observation of a single player's match activity by one observer (Reilly & Thomas, 1976). Diagrams on the pitch were used with markings and cues used to estimate distances travelled. However, such methods elicit high amounts of complexity and consumption of time required for coding, analyzing and interpreting the output and thus, formed barriers for their use in professional soccer (James, 2006). Over the past two decades, technological advances have allowed for the introduction of more sophisticated semi-automatic camera systems in the form of ProZone® and Amisco®. This allows for multi-player video tracking using computer and video technology and is now one of the most comprehensive and widely used commercial tracking systems in professional soccer (Carling et al., 2008). Generally, these tracking systems require the installation of several permanent cameras fixed in optimally calculated positions to cover the entire playing area. At least two cameras will cover each player at any time whilst on the pitch to improve accuracy of tracking. The stadium and pitch are first calibrated in terms of height, length and width and transformed into a 2-dimensional model to allow player positions (x and y coordinates) to be calculated from the camera sources. Player movements can then be tracked on the video at a sampling rate of 10-25Hz (depending on the system) by computer software through either manual operation or automatic tracking processes during the game. Despite being largely computer automated, these tracking systems still require some manual input as well as continual verification by an operator to make sure that the computer program correctly tracks players.

By establishing the work rate profiles of soccer matches, these motion analysis systems allow practitioners to examine the total distance covered by individual players and teams during the matches. Additionally, movement activities are generally coded to their time spent at an intensity, which is determined by the speed of actions. Therefore, distances are often categorised into different speed categories related to soccer and also the time spent in each category. Di Salvo and colleagues (2006) produced a validation study of ProZone® system in its application to monitoring soccer specific actions of six male subjects performed in an elite stadium setting. Subjects performed a course of various soccer specific actions including linear sprints and change of direction comparing the activity data to timing gate measurements. Correlation coefficients and absolute reliability coefficients between velocity measurements over runs of 50 and 60 m meters obtained from both systems were high ($r=0.999$; total error 0.05, limits of agreement 0.12). Therefore, such camera tracking systems were found to have an acceptable level of validity and reliability in tracking soccer specific movements and have gone on to be utilised during each competitive game in elite professional soccer (Barnes et al., 2014).

Although the practicality of this monitoring strategy is not very labor intensive for the clubs who use the data, there is a large cost associated with the installation and subscription to the tracking systems. Additionally, this information cannot yet be viewed real-time and there are large wait times (often 24-36-h post game) in order for the dataset to be available to analyze. Both of the aforementioned points give reasons for the lack of use for training sessions as this type of monitoring requires cheaper and faster analysis of training demands. Also, the reliance on trained observers and analysts still has some potential for human error in coding activates from the computer software.

2.2.5. SUMMARY

Soccer training does not near recreate the load experienced during match play. It is however, a complex process that can be monitored numerous ways, which can have an effect on the way training load is perceived. Additionally, training load can be different depending on the coach, the player's position, the players' stating status in the team and of course the weekly match schedule. In addition to modulating components of physical fitness, such factors may have also have implications for the nutritional requirements of training. As such, the nutritional requirements of soccer players will now be reviewed in the next section.

2.3. NUTRITIONAL DEMANDS OF SOCCER

2.3.1. OVERVIEW OF METABOLIC DEMANDS OF MATCH PLAY

The high levels of aerobic energy production in soccer and the pronounced anaerobic energy turnover during periods of match play are associated with the consumption of large amounts of substrates (Bangsbo, 1994). Carbohydrates are the major energy source for moderate to high-intensity exercises (>70% VO_2max) (van Loon et al., 2001) although CHO that is stored as muscle glycogen is limited to around 500 g and is depleted after soccer match play

(Saltin, 1973). Conversely, the supply of fat sources within the body is more plentiful although fat can only supply energy for low-to-moderate intensity exercise (i.e. <60% VO_2max). For match play itself, it is therefore essential for soccer players to consume a high CHO diet to maximise muscle glycogen stores in order to maintain high-intensity performance throughout its 90 minutes duration.

In relation to sources of energy production for match play, muscle glycogen is the predominant substrate. Although there are difficulties measuring substrate utilization in soccer matches, Saltin (1973) observed that players who began a game with low (~200 mmol.kg^{-1} dw) muscle glycogen content had almost all of their stores depleted by half time. Additionally, players who began the game with high muscle glycogen stores (~400 mmol.kg^{-1} dw), still had high levels at half time, but were almost depleted (<50 mmol.kg^{-1} dw) at the end of the game. Krustrup et al. (2006) also observed that pre-game muscle glycogen was 449 ± 23 mmol.kg^{-1} d.w. and decreased to 225 ± 23 mmol.kg^{-1} dw immediately after the match. Although post-game glycogen values in whole muscle 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 and take >48h to fully resynthesise (see Figure 2.2.). As such, glycogen depletion is 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). These findings highlight the potential role of muscle glycogen depletion as a key factor contributing to nutritional-related causes of soccer specific fatigue.

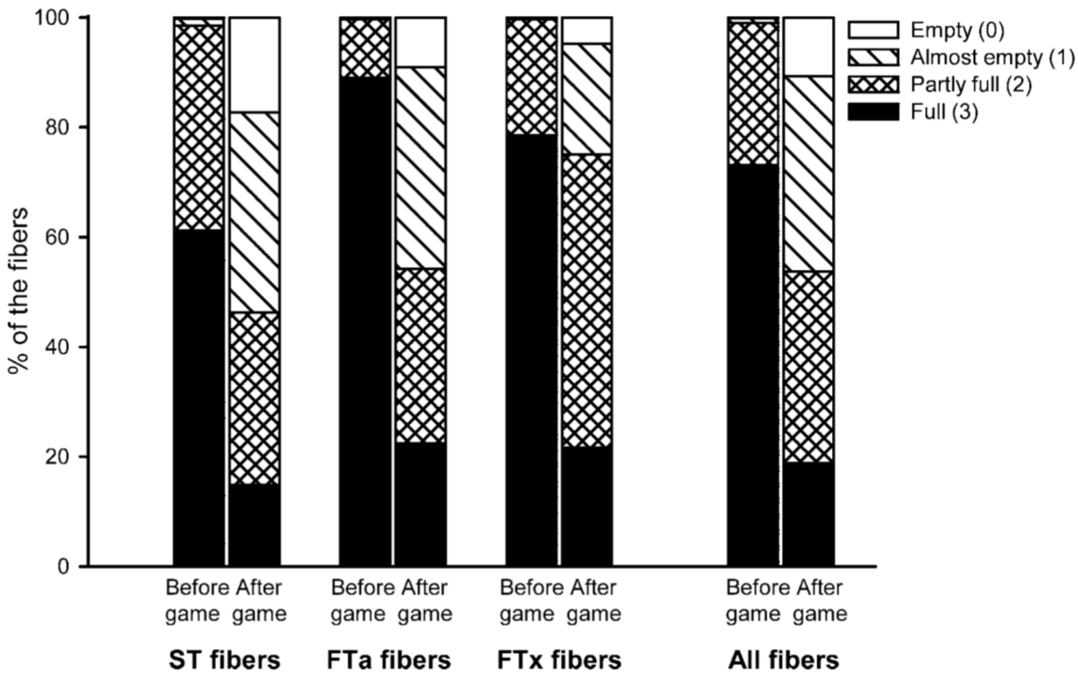


Figure 2.2. Relative glycogen content in slow twitch (ST), fast twitch type a (FTa) and fast twitch type x (FTx) fibers as well as all fibers before and immediately after a soccer match (adopted from Krustrup et al., 2006).

Given the limited capacity to store muscle and liver glycogen, it is crucial that the daily diet contains adequate CHO availability so as to effectively prepare and recover from repeated training sessions and games. Accordingly, the nutritional recommendations for optimal match performance advise high CHO availability before, during and after games (Burke et al., 2011; Burke et al., 2006). Indeed, in terms of match-specific performance, commencing match-play with elevated muscle glycogen stores increases total distance covered (Saltin, 1973) as well as high-intensity activity (Balsom et al., 1999). Furthermore, consuming additional CHO during exercise (in the form of sports drinks and gels) improves intermittent exercise capacity (Foskett et al., 2008; Nicholas et al., 1995; Phillips et al., 2012) and the ability to perform technical skills such as passing and shooting (Ali et al., 2007; Russell & Kingsley, 2014). The mechanisms underpinning enhanced performance with exogenous CHO provision may be due to factors such as prevention of hypoglycaemia, since blood glucose values <3.5 $mmol.L^{-1}$ have been observed during soccer match play (Krustup et al., 2006), as well as the maintenance of high CHO oxidation rates, muscle glycogen sparing (Convertino et al., 1996; Coyle, 2004; Coyle, 1992).

Free fatty acids (FFA) concentrations in the blood are increased during the game, but most notably in the second half (Bangsbo, 1994; Krustrup et al., 2006; see Figure 2.3.). As ~80-90% of soccer match play is covered at low to moderate intensity activity and consists of frequent breaks and rest periods (Bradley et al., 2009; Di Salvo et al., 2010; Rienzi et al., 2000), such running intensities and rest periods allow for increased blood flow to adipose tissue, which promotes the release of FFA and therefore gives an indication of lipolysis occurring in soccer match play. Furthermore, hormonal concentrations such as catecholamine concentrations are progressively elevated and insulin concentrations are lowered during match play, which stimulate a high rate of lipolysis and release FFA into the blood (Bangsbo et al., 1994; Galbo, 1983). Such progressive elevations in catecholamine during the second half may also increase the use of muscle triglycerides (Galbo, 1992). Also, due to the intermittent nature of soccer and large amounts of rest periods (i.e. a during a break in play such as a free-kick or substitution), FFA will change during a match and may cause a higher uptake and oxidation of such acids by the contracting muscles (Turcotte et al., 1991). Therefore, both forms of substrate may be used during a soccer game and the latter may be a compensatory mechanism for the lowering of muscle glycogen.

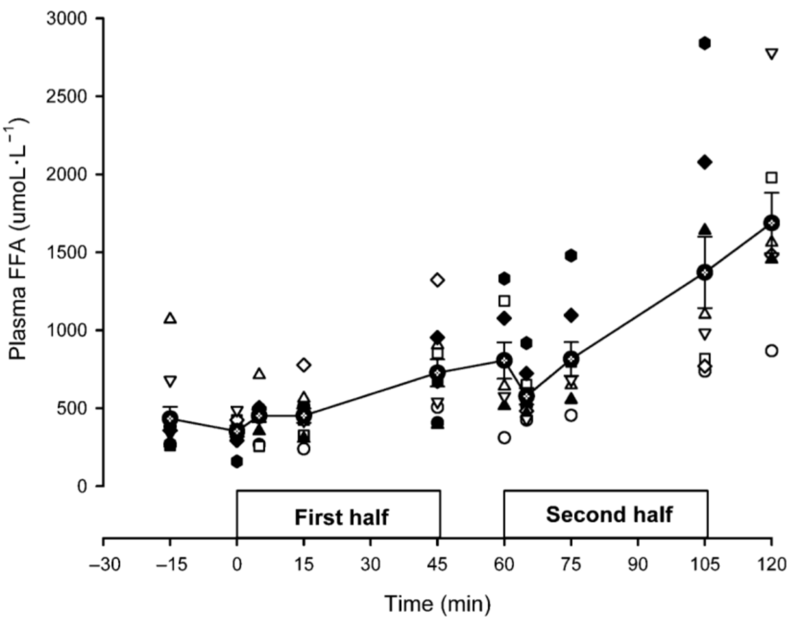


Figure 2.3. Plasma FFA concentrations before, during and after a soccer game (adopted from Krustrup et al., 2006).

2.3.2. OVERVIEW OF THE NUTRITIONAL RECOMMENDATIONS FOR MATCH PLAY

2.3.2.1. DAY PRIOR

Given the role of muscle glycogen in fuelling moderate and high-intensity exercise, the major goal of nutritional interventions in the days prior to the game should be to maximise pre-game muscle and liver glycogen stores (i.e. CHO loading). Soccer players can achieve high glycogen stores with as little as 24-36 h of a high CHO (6-10 $g.kg^{-1}$) diet (Bassau et al., 2002), providing that training demands on the day prior to match day are relatively low in volume and intensity. To be able to fully maximise muscle glycogen stores on the day before the game it is necessary to consume larger portion sizes of increased frequency that consists of mainly high glycaemic index foods and drinks (Burke et al., 1993; Wee et al., 2005).

2.3.2.2. PRE-MATCH MEAL

Soccer players often perceive the pre-match meal to be the most important for match performance as it's the closest to match play itself. However, assuming that players have correctly CHO loaded in the day and morning prior to match play, the pre-match meal is simply time to "top up" glycogen stores prior to match performance (Chryssanthopoulos et al., 2004; Wee et al., 2005). Essentially, the timing of the pre-match meal is dependent on the location and timing of kick off. For example, for a regular 3 pm Saturday kick off, nutritional preparation on match day would consist of a light breakfast and the main pre-match meal consumed around 11.30 am. Alternatively, for an evening kick off between 7.45 and 8 pm, match day nutrition would be extended and the pre-match meal should be consumed at around 4.30 pm. Finally, at the opposite end of the spectrum is the lunch time kick off (usually between 12 and 1 pm) and in this situation, match day nutrition would be limited, with breakfast effectively serving as the pre-match meal. In this case, breakfast is the opportunity to replenish the glycogen stores that are lost from the liver during an overnight fast and help "top up" muscle glycogen stores in preparation for match play (Casey et al., 2000).

Regardless of the timing of the game, it is always advised that the pre-match meal be reasonably high in CHO (approximately 2 $g.kg^{-1}$) and consumed within 3-4 hours prior to kick off so as to allow sufficient time for digestion and avoid gastrointestinal problems and feelings of gut fullness (Wee et al., 2005). It is important that the stomach be reasonably empty at the time of commencing the match so the digestion and absorption of food do not compete with the exercising muscles for blood supply. Furthermore, consumption of fibre (e.g. vegetables) and high fat foods (even those associated with protein sources such as red meat and cheese) should be avoided given that they slow down the rate of gastric emptying.

2.3.2.3. DURING MATCH

Carbohydrate intake in the correct doses during the game itself enables the player to maintain appropriate energy availability by sustaining blood glucose levels, increasing CHO oxidation and potentially sparing muscle and liver glycogen (Convertino et al., 1996; Coyle, 2004; Coyle, 1992). The addition of CHO feeding at regular intervals during simulated soccer match play after a prior CHO loading strategy improves high-intensity running capacity during simulated intermittent exercise (Foskett et al., 2008). Additionally, CHO provided during games improves aspects of technical (Ali & Williams, 2009; Russell & Kingsley, 2012) and cognitive (Welsh et al., 2002) performance. During exercise, CHO oxidation from exogenous feeding has maximal oxidation rates from glucose polymers of approximately 1 $g.min^{-1}$ (Jeukendrup, 2010), and players are therefore advised to consume 30-60 g per hour. Such doses are equivalent to 500-1000 ml of a conventional 6% sports drink though ingestion of such volumes of fluid are unlikely given that opportunities for fuelling are limited to natural breaks in match play and the half-time period.

In order to sustain plasma glucose levels and potential spare endogenous glycogen stores, it is likely required to begin fuelling from the beginning of the game in any opportunity available (i.e. immediately before players leave the changing rooms). Additionally, players should attempt to fuel again at the half-time period and at regular periods in the second half. Rates of CHO oxidation are largely similar regardless if CHO is provided in fluid, gels or sports bars (Pfeiffer et al., 2010a, 2010b) and thus players should be provided with their preferred source to encourage appropriate energy intake. The provision of gels or sports bars is particularly useful to those who prefer water for hydration as opposed to sports drinks as well as those who prefer not to drink much fluid at all.

2.3.2.4. POST-MATCH

The goal of post-match nutrition is to replenish both muscle and liver glycogen stores as well as promoting protein synthesis so as to facilitate remodeling and repair of muscle tissue. In relation to muscle glycogen 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 (Beelen et al., 2010). Importantly, post-match feeding should begin immediately (i.e. in the changing room) as this is when the muscle is most receptive to glucose uptake and the enzymes responsible for glycogen synthesis are most active (Ivy et al., 1988). Whether or not the CHO is provided in solid or liquid form is immaterial and should be left to the player's preference. In practice, therefore, a selection of high CHO snacks and drinks should be readily available in the changing room post game. Additionally, these meals should contain moderate protein intake to repair exercise induced muscle damage and post-exercise protein synthesis (Ivy, 2004; Ferguson-Stegall et al., 2011).

2.3.3. OVERVIEW OF THE METABOLIC DEMANDS OF TRAINING

Although the physical demands of match play have long been known, an increased use of contemporary tracking technologies has allowed professional clubs to easily collect objective internal and external variables of players during training (Buchheit et al., 2014). This had led to an increase in training load research in different micro-cycles (Akenhead et al., 2016; Malone et al., 2015).

Such data suggest that absolute training loads are not as high as those experienced in match play. This is the case for parameters such as total distance (e.g. <7 km vs. 10-13 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). It is therefore likely that the need for maximizing muscle glycogen stores for training days is not necessary and that a sufficient amount of CHO should be consumed in order to simply fuel training sessions. Consuming a daily diet on training days that is high in CHO and energy may lead to elevated body fat and reduced performance adaptations (Bartlett et al., 2015). Therefore, more information is required on current training load practices during typical micro-cycles experienced by elite soccer players. Such data could allow more specific nutritional guidelines in relation to CHO intake.

Although the actual energy demands of soccer training are still relatively unknown, research examining a simulated 'in season' soccer training session on a treadmill displayed a 14% reduction in muscle glycogen stores (Jeong et al., 2015. Data from this study suggest that muscle glycogen is not heavily taxed during training. However, the full demands of soccer training cannot be replicated on a treadmill due to lack of accelerations/ decelerations and change of directions. More information is required on the metabolic demands of soccer training to develop more comprehensive nutritional guidelines.

In addition to the "on pitch" endurance training and matches, soccer players are often required to perform maximal strength training sessions in the gym within the same training cycle. This is defined as 'concurrent training' (Fyfe et al., 2014). The challenge for practitioners is to design and implement concurrent training programs into the weekly micro-cycle and also facilitate this with the correct nutritional prescription. However, for soccer players this is not always systematic and players often perform strength training prior to on pitch training sessions or strength training after pitch sessions with varying recovery times in between. This can subsequently affect the habitual intakes of players, as they tend to consume protein shakes post resistance training whilst adhering to their regular meal patterns. Using an ecological valid study where participants underwent "real world" methodologies, Enright et al. (2015) performed concurrent training two-days per week when soccer training was performed prior to strength training vs. strength training being performed prior to soccer training. Enright and colleagues reported larger strength benefits when soccer training was performed in the morning, followed by lunch, strength training and a whey protein shake with exercise order being suggested the defining factor. However, the more evenly distributed protein intake across the day during this trial is also a potential factor (Areta et al., 2013; Mamerow et al., 2014). Therefore, soccer players should be advised to consider the training structure and the potential effects of protein distribution in facilitating training adaptations when advising nutritional recommendations.

2.3.4. ENERGY DEMANDS OF SOCCER PLAYERS

In addition to the metabolic demands of soccer, quantifying the total energy expenditure (EE) of soccer players is necessary in order to provide accurate nutritional programs and guidance, however in elite players, this is currently not well known. The total EE and requirements of each soccer player are unique, arising from the contribution of basal metabolic rate, thermic effect of food, thermic effect of activity, and in some cases growth (Manore & Thompson, 2006). Nowadays elite professional soccer players can undertake multiple training sessions per day and compete in two competitive matches during the weekly micro-cycle. This means that the player's EE is likely to be high and often periodised in accordance with the daily load. It is therefore essential to have an accurate understanding of EE in order to prescribe sound nutritional programs. The development of valid methods for assessing EE in soccer players is highly beneficial to the sports scientist, nutritionist, coach and player.

2.3.4.1. DOUBLY LABELED WATER

The use of the DLW for the assessment of free-living EE has been used for over three decades (Schoeller & van Santen, 1982). This technique has been widely acknowledged as the criterion or "gold standard" approach to assess EE in free-living individuals (Schoeller & Delany, 1998; Speakman & Roberts, 1995; Park et al., 2014). It provides the total energy expended over a 4-20 day period and is subsequently analysed using isotope ratio mass spectrometry (International Atomic Energy Agency, 2009)

This method of precisely measuring EE requires a player to orally consumes a single bolus of hydrogen (deuterium ^{2}H) and oxygen (^{18}O) stable isotopes in the form of water ($^{2}H_{2}{}^{18}O$). The desired dose of the isotopes is determined prior to consumption and is calculated according to body mass using the following equation:

$$^{18}O \text{ dose} = [0.65 \text{ (body mass, g) x DIE}]/\text{IE}$$

Where DIE is the desired initial enrichment (DIE = 618.923 x body mass (kg)$^{-0.305}$) and IE is the initial enrichment (10%) 100,000 parts per million.

From here, the isotopes ^{2}H (deuterium) and ^{18}O, mix with the normal hydrogen and oxygen in the body water within a few hours. As energy is expended in the body, both CO_2 and water are produced. The CO_2 is lost from the body in breath, whilst water is lost in breath, urine, sweat and other evaporations. As ^{18}O is contained in both CO_2 and water, it is lost from the body quicker than ^{2}H, which is contained in water but not in CO_2. The difference between the rate of loss of ^{18}O and ^{2}H reflects the rate at which CO_2 is produced. A plot of the change in concentrations of the two isotopes in body fluids, from which the rate of loss of these isotopes from the body fluid can be calculated, is shown in Figure 2.4.

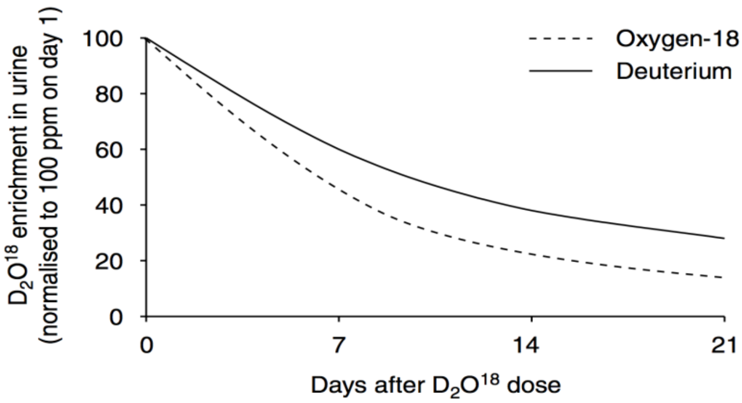


Figure 2.4. Decline of ^{2}H (deuterium) and ^{18}O in body fluids (urine, plasma or saliva) during a hypothetical doubly labeled water experiment (adopted from Ainslie et al., 2003).

To date only one study has used DLW to examine EE in soccer players (Ebine et al., 2002). This study found that EI were 14.8 ± 1.7 MJ·day^{-1} (3532 ± 408 kcal·day^{-1}) in seven male Japanese professional soccer players. Additionally, in this study there were two competitive matches during the week of testing, which is therefore likely to be more reflective of a team competing in both midweek and weekend matches.

This technique has huge advantages due to its use within free-living individuals, it is also non-invasive, imposes minimal participant burden and does not interfere with training activities (Montoye et al., 1996). Additionally, the main advantages of this method are the accuracy and precision and can certainly determine the recommended EI of free-living athletes in professional soccer (Edwards et al., 1993; Westerterp, 1999; Ebine et al., 2002). Despite being the criterion method for the assessment of EE, the DLW technique measures EE over a chosen number of days or weeks from which average daily EE can be calculated. Therefore, information on periods of high expenditure or individual training sessions cannot be examined (DeLany & Lovejoy, 1996). Additionally, the high cost of the stable isotopes and the specialised expertise required for the analysis of isotope concentrations in body fluids by mass spectrometry may also limit its application in elite soccer. Lastly, in field studies, because CO_2 production and not oxygen utilization is being measured, approximately 5% error is introduced if the respiratory quotient is not known (Westerterp, 1999). Nonetheless, results from this analysis provide the closest measure of free-living EE in athletes and can be used for a reference technique for validating estimates of energy requirements obtained via other methods (Westerterp, 2009; Westerterp & Plasqui, 2004).

2.3.4.2. HEART RATE

There is a significant relationship between HR and EE, so analysis of HR can allow for an estimate of EE to be made. This relationship stems from HR and oxygen consumption (VO_2) linearly increasing with exercise intensity up to near maximal exercise (Achten & Jeukendrup, 2003). Despite considerable inter-individual variability in the slope of HR-VO_2, the linear relationship is consistent for an individual across a range of submaximal tasks (Livingstone, 1997). Inter-individual differences are predominantly a reflection of differences in movement efficiency, age and fitness. In order to remove these inter-individual differences a calibration curve can be made based on simultaneous measurements of HR and VO_2, using indirect calorimetry in a variety of activities (Christensen et al., 1983). However, when estimating daily EE, HR does not increase as rapidly for a given change in EE, reasons for this are likely to be due to changes in stroke volume between lying, sitting and standing (see Figure 2.5.). Therefore, this method gives a potential for error and error values of up to 30% have been found in individuals (Christensen et al., 1983; Davidson et al., 1997; Livingstone, 1997).

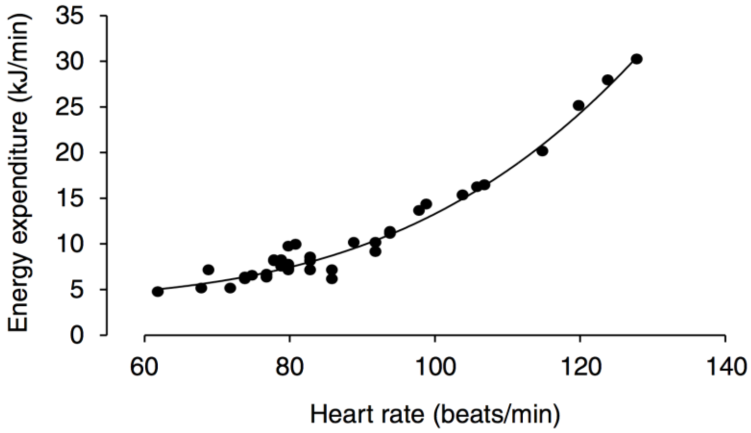


Figure 2.5. The relationship between heart rate and energy expenditure in a healthy male study participant (adopted from Ainslie et al., 2003).

The relationship between HR and energy expenditure for an individual is established using a sub-maximal calibration procedure, often performed after resting metabolic rate is determined (Hills et al., 2014). This is the optimum method for the estimation of EE and is known as the flex-HR method (Spurr et al., 1988). Here both HR and VO_2 are measured simultaneously whilst lying down, sitting, standing and performing exercise at a variety of intensities. From this, the average EE for each activity at each workload can be estimated from VO_2 and VCO_2 values using the equations of Livesey and Elia (1988). This can then be used to develop each individual's HR-VO_2 curve and a regression line of HR to EE is developed for each individual from the sub-maximal calibration procedure. The flex-HR is quantified by the average of the highest HR from resting/ sedentary activity and the lowest HR from light activity. If a given HR during field activity is below the flex-HR, the resting metabolic rate is used to determine the EE. If a given HR is above the flex-HR then the calibration curve is used to estimate EE. Consequently, this method does prove costly and time consuming. A group calibration could be used to decrease time; this can increase the reliability of EE estimation (Spurr et al., 1988).

The current literature provides a general consensus that while the HR method provides satisfactory estimates of average EE for groups of people, it is not an accurate measure for individual study participants (Spurr et al., 1988, Ceesay et al., 1989; McCrory et al., 1997). This is demonstrated by a classical study by Spurr et al., (1988) who compared 24-hour EE by calorimetry to the HR method in 22 individuals. HR values deviated from EE values from between +20 and -15%. However, due to similar average scores, the statistical significance of a paired t-test failed to observe these differences.

Heart rate monitors are portable, non-restraining, unobtrusive and cheap, with long battery lives allowing for measurements to be carried out over several days. However, it has not been common practice to use with professional soccer players to measure EE. Reilly and Thomas (1979) were the first to measure EE via a combination of HR and activities records. Similarly to the DLW results from the Japanese players, total daily EE was estimated at 14.4 MJ.day^{-1} (3442 kcals.day^{-1}). This shows a high level of consistency between results even over a gap of 23 years where significant changes could occur in training programs and demands. Additionally, the use of HR to estimate EE has been examined in top-level Brazilian professional soccer players in competitive matches (Garcia et al., 2005). Here Garcia and colleagues used indirect calorimetry prior to the matches in order to develop individual EE-HR curves. Average EE over the five games ranged between 10.9 – 11.8 kcal.min^{-1}. Over a 90-minute match, this equates to 983 – 1064 kcals and will considerably influence the total daily EE on a match day.

However, HR is affected by external factors other than physical activity. For example, physiological status, emotional stress, high humidity, dehydration, posture and illness can all have an effect on HR values without changes in VO_2 and thus, EE (Montoye et al., 1996; Christensen et al., 1983; Davidson et al., 1997; Melanson & Freedson, 1996; Spurr et al., 1988). Additionally, the size of the muscle group engaged may also affect the relationship with HR being elevated for a given VO_2 during arm exercise being different compared with exercise with the legs or with both arms (Secher et al., 1974). More specifically to soccer, the HR-EE relationship may not be as accurate as HR response relatively slowly to changes in work rate. Therefore, a sudden increase in work rate will not immediately result in the HR that would be observed at that exercise intensity after an adaption to the work rate had been allowed. Equally, when the work rate is decreased or exercised is temporarily ceased, HR will remain elevated for some time and only gradually return to the values observed during steady state conditions at this lower work rate.

2.3.4.3. ACCELEROMETRY

Motion sensor technology is an innovative, easily accessible and efficient method to objectively assess the EE of free-living individuals (Chen & Bassett, 2005). This technology allows individuals to wear sensors during most exercise activities without restricting exercise performance with large uncomfortable equipment (Chen & Bassett, 2005, Liden et al., 2002a). A relatively new product called the SenseWear™ Armband device uses a tri-axial accelerometer with other sensor technologies to obtain and collate a variety of physiological data, including galvanic skin response, skin temperature, near body ambient temperature, heat flux and sweat rate (Liden et al., 2002a). These parameters are incorporated into a patented algorithm to provide an estimate of EE (Liden et al., 2002a).

This device has been used and assessed for accuracy in numerous populations and conditions, which have provided promising results (Liden et al., 2002b, Arvidsson et al., 2007; Fruin & Rankin, 2004; Jakicic et al., 2004; Johannsen et al., 2010). However, when used to evaluate the device in an intermittent exercise drills in basketball there was a significant (~27%) underestimation of EE (Taylor, 2012). Additionally, in a rugby specific intermittent exercise protocol this device provided unclear EE during exercise and significantly overestimated during post-exercise recovery (Zanetti et al., 2014). Moreover, in rugby union players the average daily EE has been estimated at 15.9 and 14.0 MJ for forwards and backs, respectively (Bradley et al., 2015), values that were lower than when quantified using DLW (Morehen et al., 2016).

Due to the limitations with HR and that it is affected by factors other than physical activity, a method that integrates physiological and motion detection systems have been identified as a promising research area (LaMonte & Ainsworth, 2001). The Actiheart sensor is a single piece of equipment that combines HR and a movement monitor, designed to clip onto two standard electrocardiogram electrodes on the chest. This device has been found to be reliable and valid during walking and running (Brage et al., 2005). However, when assessed in free-living conditions comparing to DLW relatively poor measurement of agreements were made (Campbell et al., 2012).

2.3.5. ASSESSMENT OF DIETARY INTAKES IN SOCCER PLAYERS

The assessment of energy intake has been described as the most difficult of all physiological methods due to the difficulty of obtaining accurate and reliable data (Hackett, 2007). Given that there is no gold standard tool to assess energy intake (Hackett, 2009), the choice of method is dependent on the population being measured (Magkos & Yannakoulia, 2003). Analysis into an athlete's diet can either be done retrospectively or prospectively. Retrospective methods (i.e. dietary recall) depend on the athlete's memory and honesty to assess recent, or less recent food intakes. Prospective methods (i.e. the remote food photographic method) monitor current and ongoing food consumption but can often be underreported which raises concern for the accuracy of data collected from professional soccer players (Hackett, 2009). The major issue faced by sports nutritionists is the underreporting of dietary intake which can be explained by intentionally or unintentionally omitting some of the food consumed and/or intentionally or unintentionally reducing food intake during the study period (Magkos & Yannakoulia, 2003; Hackett, 2009). Therefore, the best option to assess dietary intake is often what suits the situation whilst clearly acknowledging the limitations of the chosen method alongside careful interpretation of the data. An overview of the most popular assessment methods used in professional soccer will now be discussed below.

2.3.5.1. DIET RECORD (FOOD DIARY)

In the dietary record approach, the respondent records the foods and beverages and the amounts of each consumed over one or more days (Thompson & Subar, 2008). Ideally, the recording is done at the time of consumption in order to avoid the reliance of memory. The amounts consumed can be measured using a variety of different ways. For example, the weighed food method is the ‘gold standard’ for assessing dietary intake although this is not always possible and other measurements such as household measures (e.g. cups or tablespoons), or estimated using pictures, or no aid are required to be used (Thompson & Subar, 2008). In order to gain an overall insight into players nutritional practices (i.e. different on a training day compared to a match day) a consecutive period of 7 days are commonly examined. In order to allow an accurate analysis of the dietary record, the player must possess a level of detail required to adequately describe the foods and amounts consumed, including the name of the food (brand name, if possible), preparation methods, recipes for food mixtures, portion size and left overs (Thompson & Subar, 2008). It is possible for the investigator to 1) provide training to the player prior to the investigation, 2) review the food diary with the player after each day of recording in order to clarify any food entries and also probe for any forgotten foods and 3) review the food diary next to a taken photograph of the consumed food so the investigator can cross examine the input method.

Although in theory this method can be very advantageous in the real world, it is not without its disadvantages. Research shows that respondent fatigue leads to an increase in incomplete records as more days of records are kept (Gersovitz et al., 1978). For example, during the latter days of a consecutive 7-day period players may develop the practice of filling out the record retrospectively rather than concurrently and in essence, becomes a 24-hour dietary recall as they are relying on memory. Additionally, recording dietary intake through this method can affect both the types of food chosen and the quantities consumed (Rebro et al., 1998; Anderson et al., 2002; Kristjansdottir et al., 2006). The conscious understanding of the intake being recorded can alter the typical dietary behaviors (Vuckovic et al., 2000). Therefore, this awareness of the diary can often give the investigator non-habitual dietary intakes and ultimately affect the reason for the investigation.

2.3.5.2. 24-HOUR RECALL

The 24-hour dietary recall method involves low subject burden, minimal distortion of food intake and are easy to administer (Hackett, 2009), and is therefore a useful assessment method to use with professional soccer players. The 24-hour dietary recall method requires players to remember and report all of the foods and beverages consumed in the preceding 24-hours or in the preceding day (Subar & Thompson, 2013). The recall is typically conducted face-to-face in an interview format and there can often be specific tools or photographs used in order to do so (i.e. a photograph of a small, medium and large bowl of cereal used to estimate portion size). This method relies on the experience and expertise of the interviewer as the player will forget a lot of foods and hence, probing questions will need to be asked. Very early research found that respondents being interviewed with the addition of probing reported ~25% higher dietary intakes than non-probed interviews (Campbell & Dodds, 1967).

The 24-hour recall can be scheduled around daily activities, conducted by a single face-to-face short interview or even by telephone or video call, meaning multiple recalls be collected, and a large number of athletes can be studied. Such methods have been shown in some situations to be more accurate than food diaries (Sawaya et al., 1996), which is likely to be due to the ability of the practitioner to extract more thorough and finer details from an athlete compared with the athlete working independently. The 24-hour dietary recall does not require any literacy of the respondent and as they are consumed after the food has been consumed and will not interfere with dietary behavior. A large disadvantage of the 24-hour dietary recall approach, like many of the assessment methods, is that players may not report their food consumption accurately for various reasons such as the player perceiving a typical food to be a poor choice so they fail to disclose this to the interviewer. Moreover, this method does not provide multiple days worth of dietary intake and multiple days of recalls may be needed in order to establish a players true eating patterns.

2.3.5.3. THE REMOTE FOOD PHOTOGRAPHIC METHOD

The remote food photographic method (RMPM) is a method that allows players to maintain free-living conditions but removes any emphasis on the player estimating portion size. This is typically done using smartphone applications where the plate of foods selected by the player and any waste following the meal are photographed and sent to the investigator at the time of consumption. This allows meals to be time stamped and puts less emphasis on player training for estimating portion sizes. The investigator will use reference or standard portions of known quantities of the foods to estimate the portion size of the foods consumed by the player. This method has been found to be highly reliable when used to measure EI in adults (Williamson et al., 2003; Williamson et al., 2004). Portion sizes from digital photography have been found to correlate highly with weighed portion sizes (r's > .90, p's < .0001) and mean difference between directly weighing foods and digital photography are minimal (< 6 g) (Williamson et al., 2003). Additionally, using the RMPM has proven to also correlate highly with weighed EI in both laboratory and free-living conditions (r's > .62, p's < .0001) (Martin et al., 2009). In the same study, this method underestimated EI by -6.6% (p = .017). More recently, Costello et al. (2017) found this method to be a accurate method to assess the diet of elite adolescent male rugby players with a small mean bias for under reporting across a 96 h assessment (CI = -5.7% to -2.2%) when compared to a researcher-observed weighed method. Therefore, this method could be considered as a potential method for estimating EI of free-living individuals, especially in athletic populations.

2.3.6. ENERGY INTAKES IN SOCCER PLAYERS

Nutritional assessments of soccer players have primarily been conducted in elite youth players with very few been conducted in senior professional players (see Table 2.3.). The most interesting conclusion from these studies is the vast amount of differences both between populations and differences in intakes over time. For example, Van Erp-baart et al. (1989) observed higher EI than Bettonviel et al. (2016), which seemingly arise from previously higher CHO, and fat intakes. Interestingly, in the aforementioned studies protein intake has remained similar whereas in professional players from the U.K. protein intake has substantially increased (Ono et al., 2012; Reeves & Collins, 2003) from previous years (Maughan, 1997). Such differences between eras are potentially driven by the increased scientific research and resulting athlete (and coach) awareness of the role of protein in facilitating adaptations and recovery from both aerobic and strength training (Moore et al., 2014; McNaughton et al., 2016).

In addition to the quantification of daily energy and macronutrient intake, it is important to consider the daily "distribution" of energy and macronutrient intakes. Such rationale is well documented for CHO given the relevance of both timing and absolute CHO intakes in relation to promoting pre-match loading and post match muscle glycogen resynthesis (Ivy et al., 1988a; Ivy et al., 1988b). Similarly to CHO intake, the timing and distribution of protein doses may have more of an influential role in modulating muscle protein synthesis when compared with the absolute dose of protein intake *per se*. This effect is evident on response to both feeding alone (Mamerow et al., 2014) and post-exercise feeding (Areta et al., 2013). Previously in elite youth U.K. soccer players (Naughton et al., 2016), adult elite players of the Dutch league (Bettonviel et al., 2016) and a mixed sex cohort of multisport Dutch athletes (Gillen et al., 2016) skewed approached have been observed to protein feeding in the hierarchical order of dinner>lunch>breakfast>snacks.

2.3.7. CARBOHYDRATE PERIODISATION

Whilst the role of high CHO availability in modulating exercise performance is well documented, there is emerging evidence that deliberately restricting CHO availability around carefully selected training sessions can enhance training adaptation (Bartlett et al. 2015). Such a nutritional approach to training is often referred to as the train-low: compete high model, surmising that although high CHO availability should always be advised to promote performance, low CHO availability enhances many of the key cell signaling pathways that regulate oxidative adaptations of skeletal muscle.

In relation to endurance training, this concept has been communicated according to the principle of “fuel for the work required” whereby CHO availability is adjusted meal by meal and day by day in accordance with the upcoming training workloads (Impey et al., 2016). Such a principle may have application to professional soccer owing to the variations in training load across the weekly micro-cycle as well as the absolute weekly loads occurring in different fixture schedules e.g. one, two or three game week schedules.

Although researchers have used a variety of acute and chronic train-low interventions to investigate the efficacy of CHO restriction and periodisation, not all are practically relevant to the professional soccer player. Nonetheless, restricting exogenous CHO intake prior to and during training sessions is a potential method that professional soccer players can adopt. Indeed, when glucose is consumed before and during six weeks of high-intensity intermittent training, oxidative adaptations of the gastrocnemius and vastus lateralis muscles are attenuated (Morton et al., 2009). Additionally, CHO feedings before, during and after 2-h low-intensity cycling (50% Wmax) attenuated GLUT-4, PDK4, AMPK, CD36, CPT-1 and UCP3 mRNA abundance in the hours after exercise. Therefore, consuming a low CHO breakfast and restricting energy drinks that are often consumed during training could be a viable method to augment training adaptations.

In addition to restricting CHO prior to and during training sessions, there is also the possibility to sleep with reduced muscle glycogen. In the traditional sleep low model, athletes perform an evening training session, restrict CHO during overnight recovery and then complete a fasted training session the following morning (Bartlett et al., 2015). In this regard, when morning exercise is commenced with glycogen <200 mmol/kg dw, AMPK, p38 and p53 activation is enhanced (Steinberg et al., 2006; Chan et al., 2004; Bartlett et al., 2013). In relation to the soccer player, it could be suggested that restricting CHO intake in the afternoon and evening meal (so as to reduce absolute muscle glycogen re-synthesis) could facilitate a practical model of sleep low so that the subsequent morning training session is commenced with reduced endogenous and exogenous CHO availability. Nonetheless, prior to prescribing soccer-specific models of CHO perioidsation, there remains the definitive need to better understand the habitual training loads and energy requirements of the professional player.

2.4. SUMMARY

The physical demands of soccer match play are now well documented and hence the associated nutritional requirements also well accepted. In such situations, high CHO availability is advised before, during and after so as to achieve high muscle glycogen stores and promote performance and recovery. In contrast, the physical demands of soccer training are less understood and is thought to be affected by a multiple factors including weekly fixture schedule, player position and starting status, coaches philosophy. As such, it is currently difficult to prescribe accurate nutritional recommendations for soccer players. Through the simultaneous use of GPS technology, assessment of energy intake and energy expenditure, it is hoped that the data arising from the studies undertaken in this thesis will help to inform contemporary nutritional recommendations for elite soccer players.

Table 2.4. Reported dietary intakes of male soccer players during training (mean daily intake ± *s*) (adapted from Burke, 2006).

					ENERGY		CHO			PROTEIN			FAT	
Reference	**Team population**	**Survey method**	**Age (years)**	**BM (kg)**	**MJ**	**KJ/kg**	**g**	**g.kg**	**%E**	**g**	**g.kg**	**%E**	**g**	**%E**
Jacobs *et al.,* (1982)	Swedish professional players (*n* = 15)	7 day food diary (household measures)	24	74	20.7 ± 4.7	282	596 ± 127	8.1	47 ± 3	170 ± 27	2.3	13.5 ± 1.5	217 ± 36	29 ± 8
Van Erp-baart et al., (1989)	Dutch elite level soccer players (n = 20)	4- 7-day food diary (household measures)	20	74	14.3	192	420	5.6	47	111	1.5	13	134	35
Caldarone et al., (1990)	Italian professional soccer players (n =33)	7-day dietary recall (household measures)	26	76	12.81 ± 2.37	169	440	5.9	56	-	-	-	-	-
Bangsbo et al., (1992b)	Danish professional soccer players (n = 7)	10-day food diary (household measures0	23	77	15.7	204	426	5.5	46	144	1.9	16	157	38
Schena et al., (1995)	Italian professional soccer players (n = 16)	7-day food diary (household measures)	25	74	13.44 ± 1.48	180	454 ± 32	6.3	57	86 ± 16	1.2	19	90 ± 14	24
Giada et al., (1996)	Italian professional soccer players (n = 23)	4-day food diary (household measures)	25	71	15.26 ±1.81	213	532	7.4	56	-	-	-	-	-
Maughan (1997)	Scotish Premier League players-two clubs (n = 51)	7 day weighed food diary	23 ± 4	80	11.0 ± 2.6	137	354 ± 95	4.4	51 ± 8	103 ± 26	1.3	16 ± 2	93 ± 33	31 ± 5
			26 ± 4	75	12.8 ± 2.2	171	397 ± 94	5.3	48 ± 4	108 ± 20	1.4	14 ± 2	118 ± 24	35 ± 4
Rico-Sanz et al., (1998)	Puerto Rico Olympic team soccer players (n = 8)	12-day food diary (household measures	17	63	16.52 ± 4.48	260 ± 50	526 ± 62	8.3	53 ± 6	143 ± 23	2.3	14 ± 2	142 ± 17	32 ± 4
Ebine et al., (2002)	Japanese professional soccer players (n = 7)	7-day food diary (household measures)	22	70	13.0 ± 2.4	186	-	-	-	-	-	-	-	-
Ruiz et al., (2005)	Basque club players (n = 24)	3 day weighed food diary	21	73	12.7 ± 2.9	173 ± 43	334 ± 78	4.7 ± 1.0	45	133 ± 31	1.8 ± 0.5	18	128 ± 49	38
Reeves & Collins (2003)	English Professional players (n = 21)	7-day food diary	20 ± 3	74	12.8	-	437	5.9	57	115	1.6	1	94	28
Iglesias-Gutierrez *et al.,* (2005)	Spanish academy players (*n* = 33)	6 day weighed food diary	14-16	65	12.6	194	364	5.6	45	123	1.9	16	127	38
do Prado *et al.,* (2006)	Brazilian professional players (n = 15)	Habitual food inquiry	-	-	12.4	-	-	-	59	-	-	20	-	26
do Prado *et al.,* (2006)	Brazilian professional players (n = 28)	Habitual food inquiry	-	-	8.3	-	-	-	52	-	-	19	-	34

do Prado *et al.,* (2006)	Brazilian professional players (n = 8)	Habitual food inquiry	-	-	16.3	-	-	-	57	-	-	13	-	30
do Prado *et al.,* (2006)	Brazilian professional players (n = 18)	Habitual food inquiry	-	-	15.2	-	-	-	54	-	-	18	-	30
do Prado *et al.,* (2006)	Brazilian professional players (n = 17)	Habitual food inquiry	-	-	14.1	-	-	-	52	-	-	19	-	26
Caccialanza *et al.,* (2007)	Italian Serie A academy players-tested twice (*n* = 75)	4 day food diary (household measures)	16	70	10.7 ± 2.6	156 ± 44	339 ± 89	4.9 ± 1.5	53 ± 4	101 ± 23	1.5 ± 0.4	17 ± 2	87 ± 25	31 ± 3
			16	71	11 ± 2.5	158 ± 41	352 ± 86	5.0 ± 1.3	53± 6	104 ± 28	1.5 ± 0.4	17 ± 2	87 ± 26	30 ± 4
Garrido *et al.,* (2007)	Spanish La Liga academy players-two groups (*n* = 62)	5 day food weighed food diary	17	74	11.5 ± 2.2	158 ± 35	316 ± 70	4.4 ± 1.1	50	111 ± 23	1.5 ± 0.3	15	101	36
			16	71	13.2 ± 2	189 ± 42	392 ± 85	5.6 ± 1.4	46	114 ± 22	1.6 ± 0.3	16	114	38
Chryssanthopoulos *et al.,* (2009)	Greek semi professional soccer players (*n* = 12)	7 day food diary (household measures)	25	72	11.8 ± 0.4	163 ± 6	305 ± 12	4.2 ± 0.1	43 ± 1	117 ± 6	1.6 ± 0.1	17 ± 1	123 ± 7	39 ± 1
Iglesias-Gutierrez *et al.,* (2011)	Spanish academy players (*n* = 87)	6 day weight food diary	18	73	11.7 ±2.2	161± 35	338 ± 70	4.7 ± 1.1	45 ± 5	119 ± 24	1.6±0 .4	17±2	116± 30	37±5
Russel & Pennock (2011)	English Championship academy players (*n* = 10)	7 day food diary (household measures)	17	68	11.9 ± 0.7	177 ± 12	393 ± 18	5.9 ± 0.4	56 ± 1	114 ± 8	1.7 ± 0.1	16 ± 1	100 ± 9	31± 1
Ono *et al.,* (2012)	English football league players (*n* = 24)	4 day food diary (household measures)	-	-	-	-	505 ± 120	-	-	141 ± 23	-	-	-	-
Briggs et al., (2015)	English Premier League Academy Players	7 day weighed food diary and 24-hr recall	15	58	9.4 ± 1.3	162 ± 23	318 ± 24	5.6 ± 0.4	55 ± 3	86 ± 10	1.5 ± 0.2	16 ± 1	70 ± 7	29 ± 2
Bettonviel et al., (2016)	Eredivisie Elite players (*n* = 29)	24 hour dietary recall	20 ± 4	73 ± 8	12.4 ± 2.2	170	384 ± 84	5.4 ± 1.3	52 ± 6	132 ± 26	1.8 ± 0.4	18 ± 3	90 ± 21	27 ± 4
Naughton et al., (2016)	English Youth soccer players (*n* = 59)	7 day food diary (household measures)	12.7 ± 0.6	45 ± 7	7.9 ± 1.8	177	266 ± 58	6.0 ± 1.2	-	97.3 ± 21	2.2 ± 0.5	-	56.1 ± 17.5	1.3 ± 0.5
			14.4 ± 0.5	60 ± 8	8.1 ± 1.3	134	275 ± 62	4.7 ± 1.4	-	96.1 ± 13.7	1.6 ± 0.3	-	55.2 ± 10.6	0.9 ± 0.3
			16.4 ± 0.5	70 ± 8	8.2 ± 1.6	117	224 ± 80	32. ± 1.3	-	142.6 ± 23.6	2.0 ± 0.3	-	60 ± 14.7	0.9 ± 0.3

Abbreviations: BM = body mass, CHO = carbohydrate.

CHAPTER 3

GENERL METHODOLOGY

This chapter provides details of methods that were employed in the experimental studies undertaken in this thesis . Methods that were unique to a particular study are presented in the methods section of that particular chapter.

3.1. ETHICAL APPROVAL AND LOCATION OF TESTING

The local ethical committee of Liverpool John Moores University approved all of the studies in this thesis. All subjects were fully informed of the nature of the testing, both verbally and in writing, and were free to withdraw at any time during the studies. Training load data collection took place on the grass pitches at Liverpool Football Club training facilities in Liverpool, England (Figure 3.1.). Match load data collection took place at both home (Figure 3.2.) and away grounds in the English Football League, respectively.

Figure 3.1. Liverpool Football Club training facilities used for training load data collection in studies 1, 2 and 3.

Figure 3.2. Liverpool Football Club's home stadium used in studies 1, 2 and 3 for collection of physical variables in official games.

3.2. PARTICIPANTS

All players were from the same professional male soccer team. The total number of players participating in these studies was 25. The characteristics of the players who took part in the 5 studies is shown in Table 3.1. For inclusion in Study 1 players had to undergo ≥75 minutes in the competitive match and complete every training session in the weekly micro-cycle analysed. All players in the outfield playing squad were included in study 2 apart from long-term injured players (>4 weeks). Players were then split into the three groups depending on whether they started games. Starting players (n=8) started ≥60% competitive games, fringe players (n=7) started 30-60% of games and non-starting players (n=4) started <30% of games. All players (n=6) volunteered for Study 3 and never withdrew consent for the duration of data collection.

Table 3.1. Summary of participant characteristics from all five studies. Data are means ± SD.

	N	Age (years)	Height (m)	Weight (kg)
Study 1 (Chapter 4)	12	25 ± 5	1.80 ± 0.05	81.5 ± 7.5
Study 2 (Chapter 5)	19	25 ± 4	1.79 ± 0.06	80.6 ± 8.3
Study 3 (Chapter 6)	6	27 ± 3	1.80 ± 0.07	80.5 ± 8.7
Study 4 (Chapter 7)	1	27	1.91	86.1
Study 5 (Chapter 8)	1	23	1.79	77.0

3.3. ASSESSMENT OF BODY COMPOSITION

During studies 3, 4 and 5 players underwent a whole body fan beam Dual-energy X-ray absorptiometry (DXA) measurement scan (Hologic, QDR Series, Discover A, Bedford, MA, USA) to obtain body composition, where the effective radiation dose was 0.001 mSv per person. The same trained operator performed all scans at the same time of day (approximately within 1 hour of waking) in a rested and fasted state (Nana et al., 2012, 2013, 2014; Rodriquez-Sanches & Galloway, 2014). Participants wore shorts only and removed any metal and jewellery prior to assessment. Height (determined by stadiometry) and scale mass (Seca, Hamburg, Germany) were recorded to the nearest 0.5 cm and 0.1 kg, respectively. Data included for analysis included percent body fat and both whole-body estimates of fat and lean mass. In study 5, regional estimates of fat and lean mass were included for analysis.

3.4. QUANTIFICATION OF TRAINING AND MATCH LOAD

Each player's physical activity during each training session was monitored using portable GPS units (Viper pod 2, STATSports, Belfast, UK). This device provides position, velocity and distance data at 10 Hz. Each player wore the device inside a custom made vest supplied by the manufacturer across the upper back between the left and right scapula. This position on the player allows the GPS antenna to be exposed for a clear satellite reception. These devices have been found to perform favorably when compared with other brands of GPS device with a typical error of measurement of <1.7% being observed throughout a range of soccer-specific activities (technical report available from http://www.marathoncenter.it/). This type of system has also previously been shown to provide valid and reliable estimates of instantaneous and constant velocity movements during linear, multidirectional and soccer-specific activities (Coutts & Duffield, 2008; Castellana et al., 2011; Varley et al., 2012). All devices were activated 30-minutes before data collection to allow acquisition of satellite signals, and synchronise the GPS clock with the satellite's atomic clock (Maddison & Ni Mhurchu, 2009). Following each training session, GPS data were downloaded using the respective software package (Viper PSA software, STATSports, Belfast, UK) and were clipped to involve the main team session (i.e. the beginning of the warm up to the end of the last organised drill). In order to avoid inter-unit error, players wore the same GPS device for each training sessions (Buchheit et al., 2014a; Jennings et al., 2010).

Each player's match data were examined using a computerised semi-automatic video match-analysis image recognition system (Prozone Sports Ltd®, Leeds, UK) and were collected using a previously validated method, as per Bradley et al. (2009). This system has previously been independently validated to verify the capture process and subsequent accuracy of the data (Di Salvo et al., 2006; Di Salvo et al., 2009). The results from this validation provided excellent correlation

(r = 0.999; Total error 0.05, Limits of agreement 0.12) with average velocity measured by timing gates. Similar correlations were also found with 15m sprints (r = 0.970; Total error 0.23, Limits of agreement 0.85) and maximal 20m sprints with left or right turns (r = 0.960; Total error 0.05, Limits of agreement 0.12). Prozone systems were used throughout the thesis to quantify all physical loading in matches. This system was used, as FIFA rules during the time of data collection did not allow for the use of GPS in competitive matches.

Variables that were selected for analysis included duration, total distance, average speed (total distance divided by training duration) and 6 different speed categories. In studies 1 and 4, these speed categories were broken down into the following thresholds: standing (0-0.6 $km \cdot h^{-1}$), walking (0.7-7.1 $km \cdot h^{-1}$), jogging (7.2-14.3 $km \cdot h^{-1}$), running (14.4-19.7 $km \cdot h^{-1}$), high-speed running (19.8-25.1 $km \cdot h^{-1}$), and sprinting (>25.1 $km \cdot h^{-1}$). In studies 2 and 3, running, high-speed running and sprinting were the only speed thresholds selected for analysis. The speed thresholds for each category are similar to those reported previously in match analysis research (Bradley et al., 2009; Mohr et al., 2003; Rampinini et al., 2007) and are commonly used day to day in professional soccer clubs. Thresholds were optional to change for GPS units, however, in order to provide continuity between both systems and when comparing to previous research I used the aforementioned speed thresholds. Additionally, numerous variables are now available with commercial GPS devices, including acceleration and decelerations efforts and the estimation of metabolic power (Gaudino et al., 2013). However, GPS technology may be unsuitable for the measurement of instantaneous velocity during high-magnitude (>4m/s^2) efforts (Akenhead et al., 2014). With regards to metabolic power, no study at present is yet to fully quantify the reliability and validity of such measures using commercial GPS devices. Additionally, obvious implications of the interchangeability between GPS and Prozone systems require caution when interpreting discrete movements such as accelerations and decelerations. Therefore, only total distance and distances covered at the aforementioned intensities are used throughout this thesis. In study 1, in addition to the absolute distance covered within each speed zone, the distance completed within each zone was also calculated as a percentage of total distance completed so as to create an “intensity distribution profile”.

3.5. MEASUREMENT OF ENERGY EXPENDITURE USING DOUBLY LABELED WATER (DLW)

Energy expenditure was determined by using the DLW method. On the day prior to start of data collection of the study, between the hours of 1400 to 1600, players were weighed to the nearest 0.1kg (SECA, Birmingham, UK). Baseline urine samples were then provided and collected into a 35 ml tube. Following collection of baseline samples, players were administered orally with a single bolus dose of hydrogen (deuterium ^{2}H) and oxygen (^{18}O) stable isotopes in the form of water ($^{2}H_2{}^{18}O$) before they left the training ground. Isotopes were purchased from Cortecnet (Voisins-Le-Bretonneux-France). The desired dose was 10% ^{18}O and 5% Deuterium and was calculated according to each participants body mass measured to the nearest decimal place at the start of the study, using the calculation:

$$^{18}O \text{ dose} = [0.65 \text{ (body mass, g) x DIE}]/\text{IE},$$

where DIE is the desired initial enrichment (DIE = 618.923 x body mass (kg)$^{-0.305}$) and IE is the initial enrichment (10%) 100,000 parts per million.

To ensure the whole dose was administered, the glass vials were refilled with additional water which players were asked to consume. The following morning (between 09:00-10:00) baseline weight samples were taken (SECA, Birmingham, UK). Approximately every 24-hour, when players entered the training ground (or hotel on the morning of game 2) they were weighed and provided a urine sample in a 35 ml tube. This urine sample was not the first sample of the day after waking as this was acting as a void pass throughout the study. Urine samples were stored and frozen at -80°C in airtight 1.8 ml cryotube vials for later analysis.

For the DLW analysis, urine was encapsulated into capillaries, which were then vacuum distilled (Nagy, 1983), and water from the resulting distillate was used. This water was analysed using a liquid water analyser (Los Gatos Research; Berman et al., 2012). Samples were run alongside three laboratory standards for each isotope and three International standards (Standard Light Artic Precipitate, Standard Mean Ocean Water and Greenland Ice Sheet Precipitation; Craig, 1961, Speakman, 1997) to correct delta values to parts per million. Isotope enrichments were converted to EE using a two-pool model equation (Schoeller et al., 1986) as modified by Schoeller (1988) and assuming a food quotient of 0.85. The results from the EE data are expressed as a daily average from the 7-day data collection period.

Doubly labeled water was used as it is the 'gold standard' in assessing EE in free-living conditions (Ainslie et al., 2003). It doesn't interfere with training or matches and was therefore ideal to use in a professional soccer setting. Although DLW is the gold standard of assessing EE, when validated and compared with a respiration chamber, it was found that this method has a precision of 2-8% depending on the isotope dose and length of the elimination period (Schoeller, 1988). Additionally, in a more recent validation, the DLW method was found to be ~1-5% accurate, ~8% precision and intraclass correlation coefficients (R=0.87-90) compared with whole-room indirect calorimetry (Melanson et al., 2017).

3.6. ASSESSMENT OF TOTAL DIETARY INTAKE

Self-reported EI was assessed from 7-day food diaries for all players and reported in kilocalories (kcal) and kilocalories per kilogram of lean body mass (kcal.kg LBM). Macronutrient intakes were also analysed and reported in grams (g) and grams per kilogram of body mass ($g.kg^{-1}$). The period of 7 days is considered to provide reasonably accurate estimations of habitual energy and nutrient consumptions whilst reducing variability in coding error (Braakhuis et al., 2003). On the day prior to data collection, food diaries were explained to players by the lead researcher and an initial dietary habits assessment (24 h food recall) was also performed. These assessments were used to establish habitual eating patterns and subsequently allow follow up analysis of food diaries. Additionally, they helped to retrieve any potential information that players' may have missed on their food diary input. Energy intake was also cross referenced from the RFPM in order to have a better understanding of portion size and/ or retrieve any information that players' may have missed on their food diary input. This type of method has been shown to accurately measure the EI of free-living individuals (Martin et al., 2009). To further enhance reliability, and ensure that players missed no food or drink consumption, food diaries and RFPM were reviewed and cross-checked using a 24-hour recall by the lead researcher after one day of entries (Thompson & Subar, 2008). As such, the lead researcher used these three sources of energy (i.e. food diaries, 24 h recall and RFPM) intake data in combination to collectively estimate daily energy and macronutrient intake / distribution. To obtain energy and macronutrient composition, the Nutritics professional dietary analysis software (Nutritics Ltd, Ireland) was used.

Energy and macronutrient intake was further assessed in relation to timing of ingestion. Meals on training days were split into breakfast, morning snack, lunch, afternoon snack, dinner and evening snack. Time and type of consumption was used to distinguish between meals; breakfast (main meal consumed between 6-9.30am), morning snack (foods consumed between the breakfast main meal and the lunch), lunch (main meal consumed between 11.30-1.30pm), afternoon snack (foods consumed between lunch and dinner), dinner (main meal consumed between 5-8pm), and evening snack (foods consumed after dinner and prior to sleep).

Meals on match days were split into pre-match meal (PMM), pre-match snack (PMS), during match (DM), post-match (PM) and post-match recovery meal (PMRM). Timing of events was used to distinguish between meals on match days; PMM (main meal consumed 3 hours prior to kick off), PMS (foods consumed between the PMM and entering the changing rooms after the cessation of the warm up), DM (foods consumed from when the players entered the changing rooms after the warm up until the final whistle or until they were substituted), PM (foods consumed in the changing rooms after the match), PMRM (main meal consumed <3 hours after the end of the match).

Throughout the duration of this study, meals were consumed at the club's training ground or home ground, a nearby hotel (where the players often reside on match day) or alternatively, the players' own homes or restaurants / cafes. For meals provided at the training ground, home ground or hotel, menus are provided on a buffet style basis where the options provided are dictated by the club nutritionist and catering staff. Throughout the duration of the study, all meals were consumed ad libitum and it was not compulsory to eat the meals provided at the training / home ground or hotel. Whenever the team stayed in a hotel, the club's chef would travel and oversee the food preparation in order to ensure consistency of service provision.

On days 3 and 6, players were provided with breakfast and lunch at the training ground whilst on days 1 and 4 players were provided with lunch and dinner at the training ground. On day 2, players were provided with breakfast at the training ground and lunch and pre-match meal at a nearby hotel, which the club uses for each home game. On day 5, players were provided with breakfast and pre-match meal at the hotel. On day 7, players were provided with a lunch and post training snack at the training ground and an evening meal at an away game hotel.

Breakfast options available daily included: eggs, beans, toast, porridge, muesli, fruits and yoghurts. Lunch and dinner had different options that included 1 x red meat option, 1 x poultry option, 1 x fish option, 3-4 CHO options (e.g. pasta, rice, potatoes, quinoa), 2 x vegetable options alongside a salad bar and snacks such as yoghurts, nuts, cereal bars and condiments. During training sessions, players were provided with low calorie isotonic sports drinks (Gatorade G2), water and upon request, isotonic energy gels (Science in Sport GO Isotonic Gels). During games, players were provided with sports drinks (Gatorade Sports Fuel), water and isotonic energy gels (Science in Sport GO Isotonic Gels). All CHO provided during training and matches were consumed *ad libitum.*

Although there is no gold standard for assessing EI, we chose three common methods for EI assessment. Food diaries have been found to have a moderate mean bias for under-reporting across 96h (-2.89 $MJ \cdot day^{-1}$; 95% CI for bias= -

17.9% to -10.2%; p<0.001). In contrast the RFPM has reported a small mean bias for underreporting across 96h for EI (-0.75 $MJ \cdot day^{-1}$; 95% CI for bias= -5.7% to -2.2%, p<0.001) compared with a previously observer weighed method (Costello et al. 2017). Additionally, 24h recalls can try to remove any additional information that was forgot or left out from players. In house work was conducted to ensure inter-researcher reliability of the methods was acceptable.

3.7. INTER-RESEARCHER RELIABILITY OF THE ENERGY INTAKE METHODS

To assess inter-researcher reliability of EI data collection, three researchers (one of whom was independent) individually assessed EI data for one day of one player selected at random. No significant difference was observed (as determined by one-way ANOVA) between researchers for energy (P=0.95), CHO (P=0.99), protein (P=0.95) or fat (P=0.80) intake. Daily totals for researchers 1, 2 and 3 were as follows: EI = 3174, 3044 and 3013 kcals; CHO = 347, 353 and 332 g; protein = 208, 201, and 194 g and fat = 106, 92 and 101 g, respectively.

CHAPTER 4

QUANTIFICATION OF PHYSICAL LOAD DURING ONE, TWO AND THREE GAME WEEK SCHEDULES IN PROFESSIONAL SOCCER PLAYERS FROM THE ENGLISH PREMIER LEAGUE: IMPLICATIONS FOR CARBOHYDRATE PERIODISATION

The aim of this chapter was to examine physical loading practices in an English Premier League club during three different weekly micro-cycles consisting of different game frequencies. The full manuscript was published in the Journal of Sports Sciences November 2015.

4.1. ABSTRACT

Muscle glycogen is the predominant energy source for soccer match play though its importance for soccer training (where lower loads are observed) is not well known. In an attempt to better inform CHO guidelines, physical load in English Premier League soccer players (n=12) was quantified during a one, two and three game week schedule (weekly training frequency was four, four and two sessions, respectively). In a one game week, training load was progressively reduced ($P<0.05$) in three days prior to match day (total distance = 5223 ± 406 m, 3097 ± 149 m and 2912 ± 192 m for days 1, 2 and 3, respectively). Whilst daily training load and periodisation was similar in the one and two game weeks, total accumulative distance (inclusive of both match and training load) was higher in a two game week (32.5 ± 4.1 km) versus one game week (25.9 ± 2 km). In contrast, daily training total distance was lower in the three game week (2422 ± 251 m) versus the one and two game weeks though accumulative weekly distance was highest in this week (35.5 ± 2.4 km) and more time ($P<0.05$) was spent in speed zones >14.4 $km \cdot h^{-1}$ (14, 18 and 23% in the one, two and three game weeks, respectively). Considering that high CHO availability improves physical match performance but high CHO availability attenuates molecular pathways regulating training adaptation (especially considering the low daily customary loads reported here e.g. 3-5 km per day), daily CHO intakes could potentially be periodised according to weekly training and match schedules.

Key Words: carbohydrate, glycogen, high-intensity, periodisation

4.2. INTRODUCTION

Soccer is an invasive field game characterised by an intermittent activity profile where brief periods of high intensity anaerobic type activity are superimposed on a larger background of exercise that taxes the aerobic energy system (Drust et al., 2000). The physical demands of soccer match play are well known where players typically cover distances of 10-14 km per match (Dellal et al., 2011; Di Salvo *et al.,* 2007; Bloomfield et al., 2007; Bangsbo et al., 2006; Fernandes et al., 2007). The vast majority of this distance has been previously classified as low to moderate intensity (speeds 0–19.8 km $\cdot$ h^{-1}) (Bradley et al., 2009), whereas high-intensity running (speeds >19.8 km $\cdot$ h^{-1}) accounts for ~8% of the total distance completed (Rampinini et al., 2007).

In relation to sources of energy production for match play, muscle glycogen is the predominant substrate, so much so that 50% of muscle fibres have been classified as empty or partially empty of muscle glycogen at the end of a game (Krustrup et al., 2006). As such, glycogen depletion is commonly cited as a contributing factor for the progressive fatigue (i.e. reduction in high-intensity running) observed towards the end of a game (Bangsbo, 1994; Bangsbo et al., 1991; Mohr et al., 2003; Reilly & Thomas, 1976; Rampinini et al., 2009). Accordingly, the nutritional recommendations for optimal match play performance advise high CHO availability before, during and after games (Burke et al., 2011; Burke et al., 2006) so as to promote high muscle glycogen stores (Bangsbo et al., 1992; Balsom et al., 1999), maintain plasma glucose levels and ensure the ability to perform technical and cognitive skills (Ali & Williams, 2009; Russell & Kingsley, 2014).

In contrast to match demands, the physical demands of training in elite professional players are not currently well documented and are limited to reports of a single week exposure (Owen et al., 2014), average values over a 10-week period (Gaudino et al., 2013) and most recently, a season long analysis by our group (Malone et al., 2015). The management of training load is traditionally considered in weekly micro-cycles consisting of one game per week (i.e. Saturday-to-Saturday schedule), though it is noteworthy that elite soccer players often play two (e.g. Sunday-to-Saturday) or three (e.g. Sunday-Wednesday-Saturday) games in a seven-day period. This is largely due to involvement in numerous competitions (i.e. domestic league / cup competitions, European competitions) and periods of intense fixture schedules such as the winter period (Morgans et al., 2014a). Such scenarios place considerable demands on sports scientists to monitor and manage training load to ensure optimal match day performance and recovery (Morgans et al., 2014c; Nédélec et al., 2014) whilst also preventing injury (Dellal et al., 2015; Dupont et al., 2010) and symptoms of over-training (Morgans et al., 2014b).

Changes in game frequency and the associated training load also has obvious implications for nutritional strategies given that the metabolic demands and typical daily EE are likely to vary according to the specific weekly training scenario. This is especially important for the role of CHO given that high CHO availability will promote match day physical and technical performance while deliberately *reducing* CHO availability during training may promote training adaptations such as mitochondrial biogenesis (Bartlett et al., 2015), increase lipid oxidation (Horowitz et al., 1997) and hence, potentially maintain a desirable body composition (Morton et al., 2010; Milsom et al., 2015). Such data therefore suggest that a periodised approach to CHO intake may be beneficial in order to maximise the aforementioned factors. However, before CHO guidelines can be prescribed for elite soccer players, there is a definitive need to better understand the interaction and accumulation of both the training and match load during differing weekly fixture/training schedules.

Accordingly, the aim of the present study was to simultaneously quantify both training and match load during three different weekly game schedules. To this end, outfield players from the English Premier League were monitored during a one, two and three game per week schedule completed in the 2013-2014 season.

4.2.METHODS

4.3.1. PARTICIPANTS

Twelve elite outfield soccer players from an English Premier League team (mean ± SD: age 25 ± 5 years, body mass 81.5 ± 7.5 kg, height 1.80 ± 0.05 m) participated in this study. The participating players consisted of three wide defenders, three central defenders, three central midfielders, one wide midfielder, and two centre forwards. All subjects were familiarised with the training protocols prior to the investigation. This study was conducted according to the requirements of the Declaration of Helsinki and was approved by the University Ethics Committee of Liverpool John Moores University.

4.3.2. STUDY DESIGN

Training and match data were collected over 3 different 7-day periods during the 2013-2014 English Premier League soccer season. The weeks were taken from the calendar months April, February and December for the one, two and three game weeks, respectively. These weeks were chosen as they included the most participants for the respective weeks throughout the entire season (one game week n = 10, two game week n = 10 and three game week n = 7). Players were selected if they performed ≥75 minutes in all competitive matches during each different micro-cycle. Although there are other weeks that represent these scenarios, these 3 different weeks met the essential prerequisites in being the only 3 weeks during the in-season where players started all games and completed all training sessions during the chosen week. An overview of the schedule for each weekly micro-cycle can be found in Table 4.1. The one game week had 2 days off and 4 training days before the match. After match 1 in the two game week, there was 1 recovery day and 4 training days before match 2. After match 1 in the two game weeks, there was 1 recovery day and 1 training day before match 2 and the same schedule in between match 2 and 3. A total number of 10 training sessions (94 individual) and 6 games (51 individual) were observed during this investigation. This study did not influence or alter training sessions in any way. Training and match data collection for this study was carried out at the soccer club's outdoor training pitches and both home and away English Premier League stadiums, respectively. Training data were also analysed in relation to day of the weekly micro-cycle (i.e. day 1 and day 2) as apposed to the match day minus approach used by Malone et al. (2015). This was due to clarity in regards to examining the different weekly scenarios.

Table 4.1. Overview of the different schedules for each micro-cycle type

	Day						
Week Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**
One Game Week	**Monday** Off	**Tuesday** Off	**Wednesday** AM Training	**Thursday** AM Training	**Friday** AM Training	**Saturday** AM Training	**Sunday** PM Game
Two Game Week	**Sunday** Game	**Monday** Off	**Tuesday** AM Training	**Wednesday** AM Training	**Thursday** AM Training	**Friday** AM Training	**Saturday** PM Game
Three Game Week	**Sunday** Game	**Monday** Recovery	**Tuesday** AM Training	**Wednesday** Game	**Thursday** Recovery	**Friday** AM Training	**Saturday** Game

4.3.3. QUANTIFICATION OF TRAINING AND MATCH LOAD

Training and match data were collected and analysed as described in section 3.4.

4.3.4. STATISTICAL ANALYSIS

All the data are presented as the mean ± standard deviation (SD). For descriptive purposes, mean and (when applicable) SD values for each position are reported in the "daily" analyses, although no statistical comparison was made between positions due to a limited number of players in each position. Data were analysed using linear mixed models, with physical load parameters as the dependent variables. Day of the week was used as the fixed factor in the "daily" analyses, while week type was used as the fixed factor in the "accumulated data" analysis. A random intercept was set for each individual player in both types of analysis. When there was a significant ($p<0.05$) effect of the fixed factor, Tukey post-hoc pairwise comparisons were performed to identify which days or week types differed. Cohen's d indices were calculated for all pairwise differences to determine an effect size (ES) for each significant difference between categories of fixed factor. The absolute ES value was evaluated according to the following thresholds: < 0.2 = trivial, 0.2-0.6 = small, 0.7-1.2 = moderate, 1.3-2.0 = large, and > 2.0 = very large. The statistical analysis was carried out with R, version 3.0.3.

4.4. RESULTS

4.4.1. DAY-TO-DAY VARIATIONS IN TRAINING LOAD ACROSS ONE, TWO AND THREE GAME WEEKS

As a global index of training and match load, both total distance and average speed during training sessions and games are displayed in Figure 4.1. Statistical comparisons between days regarding total distance and average speed within each specific weekly scenario are discussed separately below. Duration of activity and distance covered within specific speed zones are also shown in Table 4.1. and 4.2., respectively. In addition to the global indices of training and match load (see below text), main effects (all $P<0.01$) across the 7-day period for distance completed within each movement category were also observed within each week (see Table 4.1. and 4.2.). For issues of brevity, pairwise comparisons between specific days are symbolised within Table 4.1. and 4.2. To avoid confusion between weeks and for presentation of data, days will be referred to as day 1, day 2 etc. as opposed to the MD minus format used by Malone et al, (2015).

4.4.2. ONE GAME WEEK SCHEDULE

There was a significant effect of day ($P<0.01$) for total distance and average speed (see Figure 4.1.A and B). Specifically, in training total distance on day 4 was slightly higher than day 3 (estimated difference: 873 m, ES=0.3) but day 5 and day 6 were both slightly lower than day 3 (-1253 m, ES=0.4 and -1438 m, ES=0.5) and moderately lower than day 4 (-2126 m, ES=0.8 and -2311 m, ES=0.8), respectively ($P<0.01$ for all comparisons). However, day 5 and day 6 displayed no significant difference from each other (-185 m, ES=0.1; $P=0.95$).

Average speed on day 4 was slightly higher than day 3 (11.4 $m.min^{-1}$, ES=0.5) but days 5 and day 6 were both moderately lower than day 3 (-17.6 $m.min^{-1}$, ES=0.7 and -27.6 $m.min^{-1}$, ES=1.1) and largely lower than day 4 (-29.0 $m.min^{-1}$, ES=1.2 and -39.0 $m.min^{-1}$, ES=1.6), respectively. Despite no significant differences in total distance between day 5 and 6, average speed was slightly lower on day 6 compared with day 5 (-10 $m.min^{-1}$, ES=0.4) thus reflective of lower training intensity ($P<0.01$ for all comparisons).

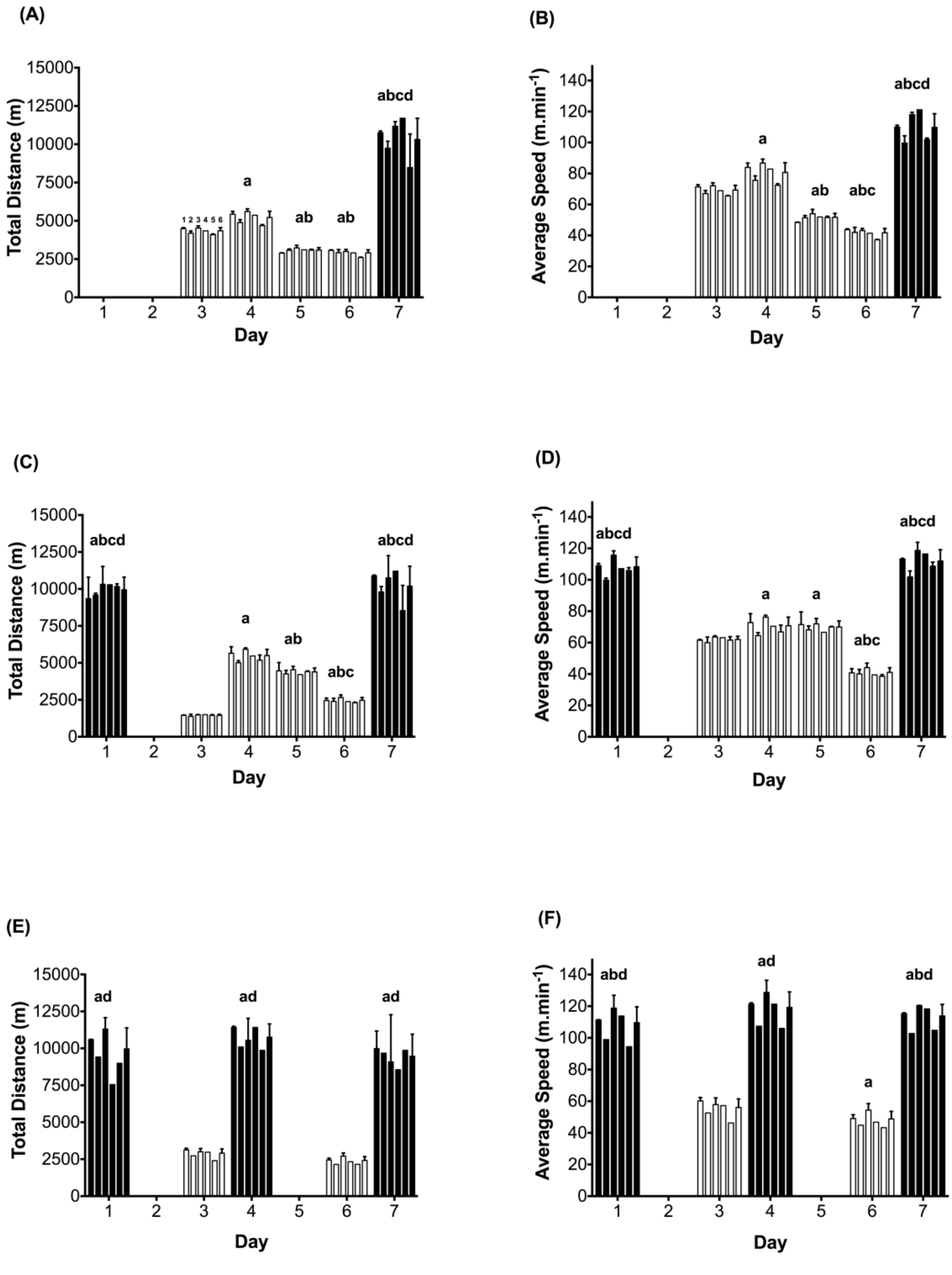


Figure 4.1. Total distance and average speed completed in training sessions and matches duration during the 7-day testing period for different positions and squad average. Figures A and B = one game week, Figures C and D = two game week and Figures E and F = three game week. Bar 1 = Wide Defender, bar 2 = Centre Back, bar 3 = Centre Midfielder, bar 4 = Wide Midfielder, bar 5 = Centre Forward, bar 6 = Squad Average (this sequence of positions is identical in all days and week types). 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 $P<0.05$.

4.4.3. TWO GAME WEEK SCHEDULE

There was a significant effect ($P<0.01$) of day for total distance and average speed (see Figure 4.1.C and D). Specifically, when compared to day 3, total distance was moderately higher on day 4 (4040 m, ES=1.2), day 5 (2943 m, ES=0.8) and day 6 (1018 m, ES=0.3) (all $P<0.01$). However, compared to day 4 total distance was slightly lower on day 5 (-1097 m, ES=0.3) and moderately lower on day 6 (-3022 m, ES=0.9). Finally, total distance on day 6 was moderately lower than day 5 (-1925 m, ES=0.6). No significant differences were present between distance covered and average speed in games on day 1 and day 7 (247 m, ES=0.1 and 3.7 $m.min^{-1}$, ES=0.1). Average speed, when compared to day 3, was slightly higher on day 4 (8.7 $m.min^{-1}$, ES=0.3) and day 5 (8.2 $m.min^{-1}$, ES=0.3) but moderately lower on day 6 (-20.1 $m.min^{-1}$, ES=0.8) compared to day 3 (all $P<0.01$). Average speed on day 6 was also moderately lower compared to day 4 (-29.7 $m.min^{-1}$, ES=1.1) and day 5 (-29.2 $m.min^{-1}$, ES=1.1) (both $P<0.01$) though no significant differences existed between day 4 and 5 (-0.5 $m.min^{-1}$, ES<0.1). No significant difference was apparent regarding average speed between games on day 1 and day 7 (3.7 $m.min^{-1}$, ES=0.1).

Table 4.2. Training and match duration during the 7-day testing periods for different positions and squad average

	Day						
	1	**2**	**3**	**4**	**5**	**6**	**7**
One Game Week							
WD	X	X	63	65	60	70	**98**
CB	X	X	63	65	60	70	**98**
CM	X	X	63	65	60	70	**95 ± 3**
WM	X	X	63	65	60	70	**97**
CF	X	X	63	65	60	70	**98**
Squad Average	X	X	63	65	60	$70^{a, b, c}$	**94 ± 9**$^{a, b, c, d}$
Two Game Week							
WD	**86 ± 14**	X	24	78	62	60	**96**
CB	**96**	X	24	78	62	60	**96**
CM	**89 ± 12**	X	24	78	62	60	**90 ± 10**
WM	**96**	X	24	78	62	60	**96**
CF	**96**	X	24	78	62	60	**78 ± 14**
Squad Average	**92 ± 9**$^{a, b, c, d}$	X	24	78^{a}	$62^{a, b}$	$60^{a, b}$	**91 ± 10**$^{a, b, c, d}$
Three Game Week							
WD	**95**	R	52	**94**	R	50	**87 ± 11**
CB	**95**	R	52	**94**	R	48	**94**
CM	**95 ± 0**	R	52	**82 ± 16**	R	50	**75 ± 26**
WM	**66**	R	52	**94**	R	50	**72**
CF	**95**	R	52	**94**	R	50	**94**
Squad Average	**91 ± 11**$^{a, d}$	R	52	**91 ± 9**^{a}	R	50 ± 1^{b}	**84 ± 15**$^{a, d}$

WD = Wide Defender, CB = Centre Back, CM = Centre Midfielder, WM = Wide Midfielder, CF = Centre Forward, X = Day Off and R = Recovery that includes a variety of activities such as cold water immersion, foam rolling, massage and pool related activities but no field based activity. **Bold** indicates data obtained from matches. ^{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 $P<0.05$.

Table 4.3. Distances covered at different speed thresholds (representative of squad average data) during training and matched completed in the 7-day testing period.

	Day						
	1	2	3	4	5	6	7
One Game Week							
Standing (0-0.6 km · h^{-1})	X	X	0	0	0	0	**26 ± 6**$^{a, b, c, d}$
Walking (0.7-7.1 km · h^{-1})	X	X	2422 ± 106	2520 ± 171	2043 ± 143$^{a, b,}$	1894 ± 117$^{a, b}$	**3756 ± 438**$^{a, b, c, d}$
Jogging (7.2-14.4 km · h^{-1})	X	X	1733 ± 171	2117 ± 388	918 ± 102$^{a, b}$	899 ± 131$^{a, b}$	**3980 ± 726**$^{a, b, c, d}$
Running (14.4-19.7 km · h^{-1})	X	X	176 ± 37	473 ± 129^{a}	130 ± 58^{b}	101 ± 46^{b}	**1559 ± 357**$^{a, b, c, d}$
HSR (19.8-25.2 km · h^{-1})	X	X	18 ± 13	96 ± 57	26 ± 28	16 ± 11	**706 ± 246**$^{a, b, c, d}$
Sprinting (>25.2 km · h^{-1})	X	X	0	6 ± 8	0 ± 1	2 ± 3	**290 ± 118**$^{a, b, c, d}$
Two Game Week							
Standing (0-0.6 km · h^{-1})	**27 ± 5**$^{a, b, c, d}$	X	0	0	0	0	**24 ± 6**$^{a, b, c, d}$
Walking (0.7-7.1 km · h^{-1})	**3579±463**$^{a, b, c, d}$	X	607 ± 45	2705 ± 161^{a}	2437 ± 77^{a}	1542 ± 126$^{a, b, c}$	**3610 ± 342**$^{a, b, c, d}$
Jogging (7.2-14.4 km · h^{-1})	**3957±394**$^{a, b, c, d}$	X	671 ± 92	220 ± 299^{a}	1564 ± 192$^{a, b}$	810 ± 126$^{b, c}$	**4016 ± 684**$^{a, b, c, d}$
Running (14.4-19.7 km · h^{-1})	**1560±274** $^{a, b, c, d}$	X	167 ± 60	455 ± 137^{a}	327 ± 76	98 ± 41 ^{b}	**1578 ± 385** $^{a, b, c, d}$
HSR (19.8-25.2 km · h^{-1})	**600 ± 205**$^{a, b, c, d}$	X	8 ± 13	104 ± 59	62 ± 29	18 ± 10	**682 ± 254**$^{a, b, c, d}$
Sprinting (>25.2 km · h^{-1})	**222 ± 120**$^{a, b, c, d}$	X	0	9 ± 18	4 ± 6	3 ± 4	**282 ± 190**$^{a, b, c, d}$
Three3 Game Week							
Standing (0-0.6 km · h^{-1})	**29 ± 10**$^{a, b, d, e}$	R	0	**18 ± 6**^{a}	R	0^{b}	**20 ± 9**$^{a, d}$
Walking (0.7-7.1 km · h^{-1})	**3593 ± 403**$^{a, d}$	R	1556 ± 68	**3714 ± 405**^{a}	R	1492 ± 105^{b}	**3473 ± 632**$^{a, d}$
Jogging (7.2-14.4 km · h^{-1})	**3783 ± 615**$^{a, d}$	R	1101 ± 200	**4083 ± 541**^{a}	R	783 ± 142^{b}	**3479 ± 591**$^{a, d}$
Running (14.4-19.7 km · h^{-1})	**1574 ± 370**$^{a, d}$	R	199 ± 63	**1764 ± 307**^{a}	R	112 ± 46^{b}	**1430 ± 295**$^{a, b, d}$
HSR (19.8-25.2 km · h^{-1})	**692 ± 197**$^{a, d}$	R	47 ± 35	**831 ± 200**^{a}	R	34 ± 29^{b}	**727 ± 236**$^{a, d}$
Sprinting (>25.2 km · h^{-1})	**291 ± 121**$^{a, d}$	R	7 ± 13	**347 ± 128**^{a}	R	0^{b}	**336 ± 138**$^{a, d}$

X = Day Off and R = Recovery that includes a variety of activities such as cold water immersion, foam rolling, massage and pool related activities but no field based activity. **Bold** indicates data obtained from matches and HSR = High-speed running. [a] denotes difference from day 3, [b] denotes difference from day 4, [c] denotes difference from day 5, [d] denotes difference from day 6 and [e] denotes difference from day 7, all P<0.05.

4.4.4. THREE GAME WEEK SCHEDULE

No significant difference was observed for total distance (589 m, ES=0.3, P=0.89) during training undertaken on days 3 and 6 though average speed was slightly lower on day 6 (-7.2 $m.min^{-1}$, ES=0.2, P<0.01). Although total distance did not differ between the 3 games undertaken, average speed was slightly higher in match 2 (day 4) compared with match 1 (day 1) (9.6 $m.min^{-1}$, ES=0.3, P<0.01) and also slightly higher than match 3 (day 7) (5.3 $m.min^{-1}$, ES=0.2, P=0.04).

4.4.5 ACCUMULATIVE WEEKLY LOADS

Weekly accumulative duration of activity, total distance and distance within specific speed zones are displayed in Figure 4.2. A-F and are inclusive of both training and matches. Figure 4.3. also displays the distance completed within each zone, as expressed as a percentage of the total distance completed. For all of the aforementioned parameters a significant effect of week was observed (all P<0.001). Duration of accumulated activity was largely higher in two game week compared with both the one game week (50 min, ES=1.7, P<0.001) and moderately higher compared to the three game week (35 min, ES=1.2, P<0.01) though no significant difference was apparent between one game week and three game week (15 min, ES=0.5, P=0.19). The two game week (7684m, ES=1.6, P<0.01) and three game week (9349m, ES= 2.0, P<0.01) produced largely higher accumulative total distance than the one game week though the three game week and two game week were not significantly different from each other (1665m, ES=0.4, P=0.13). Significant differences (P<0.01) in distance in speed zone 0-0.6 $km \cdot h^{-1}$ were present between all week types such that increasing game frequency progressively increased distance, either when expressed in absolute value or as percentage of total distance covered. Walking distance (speed zone 0.7-7.1 $km \cdot h^{-1}$) was largely higher in two game week (2012m, ES=1.3, P<0.01) and moderately higher in three game week (1627m, ES=1.0, P<0.05) compared with one game week, though no significant differences were apparent between two game week and three game week (385m, ES=0.2, P=0.79). However, when expressed as a percentage of total distance, walking distance showed an opposite tendency, being moderately higher in one game week compared to two game week (6.4%, ES =1.2, P<0.01) and largely higher when compared to three game week (9.6%, ES = 1.8, P<0.01). The difference between two game and three game weeks was small (3.2%, ES = 0.6, P<0.01). Distance covered during jogging (speed zone 7.2-14.3 km · h^{-1}) displayed a similar pattern to walking such that distance was largely higher in both two game week (3642m, ES=1.6, P<0.01) and three game week (3881m, ES=1.7, P<0.01) compared with one game week, though no significant differences were apparent between two game week and three game week (238m, ES=0.1, P=0.9). In percentage values, there was a small significant difference between two game week and one game week (1.7 %, ES = 0.6, P<0.05), while the differences between three game week and the one and two game week were not significant (<1.6 %, ES<0.5, both P>0.05).

Given the increase in game frequency, distances covered in running (speed zone 14.4-19.7 km · h^{-1}), high speed running (speed zone 19.8-25.1 km · h^{-1}) and sprinting (speed zone >25.2 km · h^{-1}) all displayed significant differences (P<0.01) between all week types both when expressed as absolute or percentage values. For running distance, two game week (1769m, ES=1.4; 3.0%, ES= 1.2) and three game week (2560m, ES=2.0; 4.6%, ES=1.8) were largely higher than one game week whilst three game week (791m, ES=0.6; 1.6%, ES = 0.6) was also moderately greater than two game week. For high speed running distance, two game week (652m, ES=0.9; 1.1%, ES = 0.6) and three game week (1417m, ES=1.9; 2.9%, ES = 1.6) were, moderately and largely higher, respectively, than the one game week whilst the three game week (764m, ES=1.0; 1.9%, ES = 1.0) was also moderately greater than two game week. Finally, for sprint distance, three game week was, respectively, largely and moderately higher than one game week (659m, ES = 1.7; 1.6%, ES = 1.6), and two game week (413m, ES=1.1; 1.1%, ES =1.1), whilst two game week was also moderately higher than one game week when examining absolute sprint distance (247m, ES = 0.6). However, only a small difference was observed between one and two game week for sprint distance as percentage (0.4%, ES = 0.4).

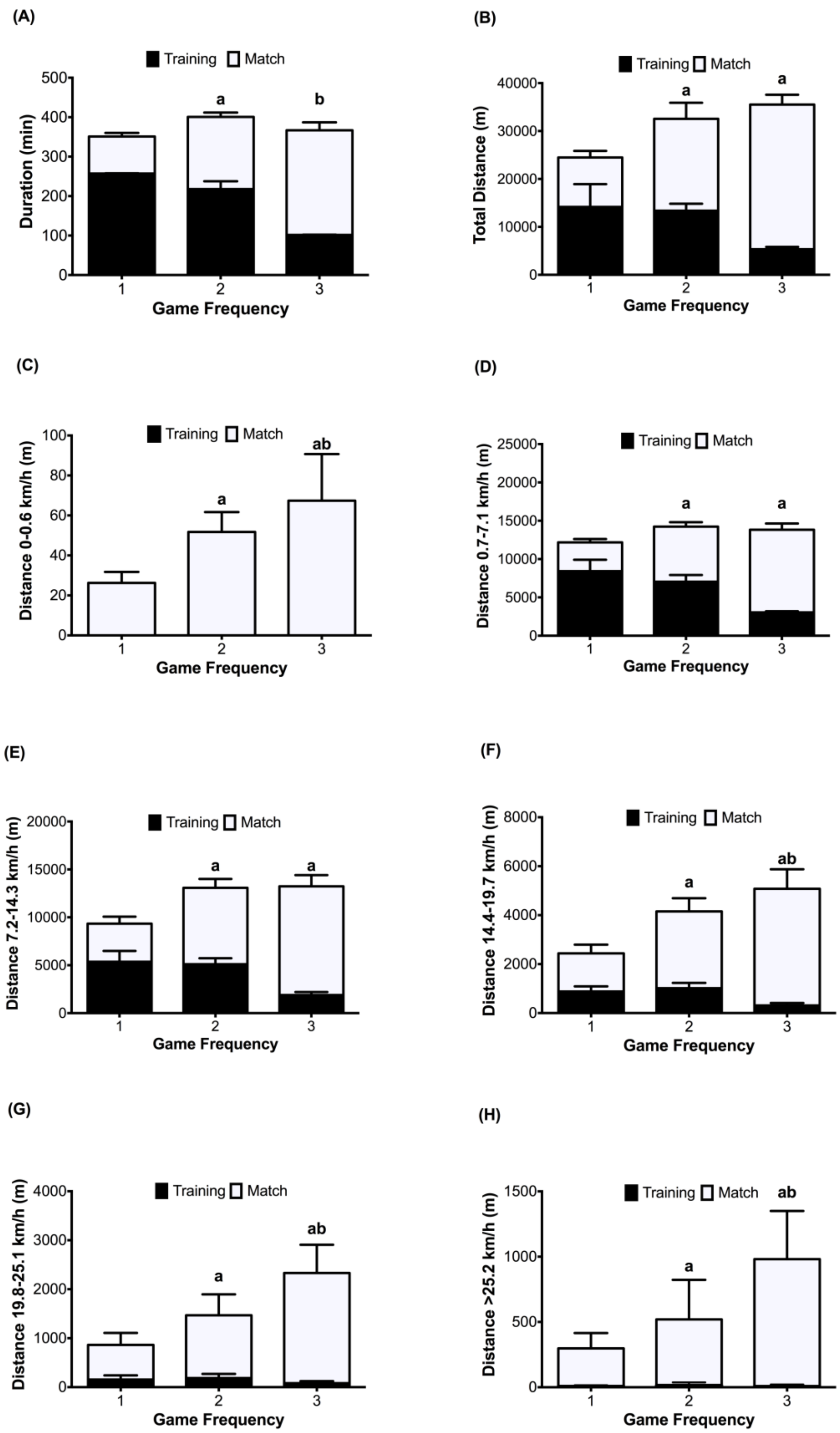


Figure 4.2. Accumulative weekly A) Duration, B) Total distance, C) Standing distance, D) Walking distance, E) Jogging distance, F) Running distance, G) High speed running distance and H) Sprint distance. [a] denotes difference from one game week, [b] denotes difference from two game week, all $P<0.05$.

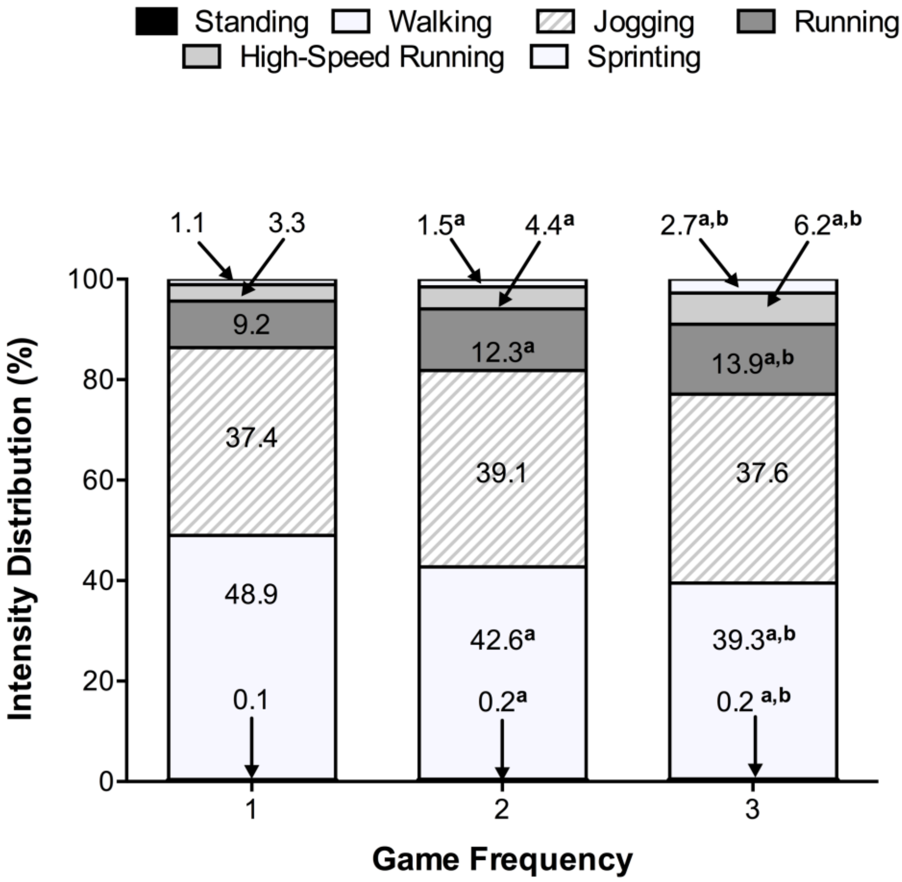


Figure 4.3. Intensity distribution expressed as percentage of distance completed within each speed zone. Numbers inset represent actual percentage values. [a] denotes difference from one game week, [b] denotes difference from two game week, all $P<0.05$.

4.5. DISCUSSION

Given that the physical match demands of elite soccer match play are well documented, nutritional strategies that emphasise high CHO availability to promote physical, technical and cognitive performance are based on sound scientific rationale. In contrast, the physical demands of the typical training sessions completed by elite level soccer players are not well defined, thereby making it difficult to prescribe daily CHO guidelines to promote fuelling, recovery and training adaptation. Additionally, the variations in fixture schedules are likely to further complicate the nutritional requirements to simultaneously promote training adaptations, match day performance and recovery. As such, a first report of daily training load and weekly-accumulated load (reflective of both training and match demands) during one, two and three game week schedules is provided above. Importantly, there were marked differences in daily and accumulated loads within and between game schedules, therefore having implications for the nutritional strategies that should be implemented in different micro-cycles of the season.

In the one game per week micro-cycle, there was clear evidence of training periodisation in the days leading into game day. For example, total distance and average speed were greatest on day 4 (5223 ± 406 m; 80.7 ± 6.3 m/min) and displayed progressive daily reductions on day 5 (3097 ± 149 m; 51.7 ± 2.5 m/min) and 6 (2912 ± 192 m; 41.7 ± 2.8 m/min), commensurate with a reduction in gross training load and intensity. Such patterns of training periodisation are different from previous observations from our group (also from the same professional club) whereby evidence of periodisation was limited to the day preceding game day only (i.e. Day 6), and was largely reflective of a reduction in training duration as opposed to alterations in loading patterns (Malone et al., 2015). Additionally, the load reported by Malone et al. (2015) was higher (e.g. daily total distance 6-7 km) than that observed here, likely due to changes in coaches in the different seasons and the sample size of the different positional groups. Similarly, total distance observed here is lower than that reported (average daily values from one week of 6871-11,860 m) in elite players from the Scottish Premier League (Owen et al., 2014) but higher than that observed in players from another English Premier League soccer team, where mean daily values of 3618-4133 m (over a 10-week period) were observed (Gaudino et al., 2013). Such data therefore clearly highlight the role of the managerial structure and coaching staff in influencing daily training loads and in turn, the daily energy and CHO cost of training.

In relation to specific training intensities, the majority of distance was completed in the low to moderate speed zones whereas the distance completed in high intensity zones were largely completed in the game itself (see Table 4.2., Figure 4.2. and Figure 4.3.). Such patterns of loading are likely a reflection of training time focusing on tactical and technical elements of match play as opposed to physical aspects of training. Additionally, these data also highlight the importance of time engaged in match play *per se* in relation to potentially maintaining the capacity to perform work in these high-intensity zones.

As expected, it was also observed that the total weekly accumulated loads were lower in the one game week schedule compared with the two and three game weeks. It is noteworthy that the total weekly load (hence energy cost) reported here is considerably lower (e.g. ~25 km) than endurance sports (Esteve-Lanao et al., 2005) where the competitive situation (like soccer) is also CHO dependent (O'Brien et al., 1993). For example, the accumulative weekly distance completed by British middle, long and marathon distance runners were 123, 138 and 107 km, respectively, when tapering for competition (Spilsbury et al., 2015). Given such differences in both daily and accumulative weekly load, it could therefore suggest that the traditional high dietary CHO guidelines (e.g. 6-10 $g.kg^{-1}$ body mass) commonly advised to endurance athletes and "team" sport athletes may not always be appropriate for professional soccer players. This is especially pertinent given recent data from our group and others demonstrating that high CHO availability may actually attenuate training-induced adaptations of human skeletal muscle (Bartlett et al., 2015). As such, the potential role of using nutritional manipulations to maximise the training stimulus perhaps becomes even more important in those situations where load is not necessarily high.

When considering the clear evidence of training periodisation between days, our data also gives reasoning to the concept of nutritional periodisation whereby high CHO availability (e.g. 6-10 $g.kg^{-1}$ body mass) is promoted on the day prior to match day (Bassau et al., 2002), on match day itself (Williams & Serratosa, 2006) and on the day after match day (Burke et al., 2006) thus promoting fuelling and recovery, whereas high CHO availability may not necessarily be required on the other training days. On the basis of the most recent CHO guidelines for training and competition that take into account both intensity and duration (Burke et al., 2011) and in conjunction with the data collected here, it could be suggested that training days incorporating single sessions can be fuelled accordingly by daily CHO intakes <4-5 $g.kg^{-1}$ body mass. However, it must be acknowledged that these suggested intakes may not be applicable for other clubs owing to the fact that different clubs may have different training structures and philosophies and players will also likely be training for different goals (e.g. losing body fat, increasing lean mass etc). Further detailed studies of daily EE (using measures such as DLW) and potentially other indicators of total load (e.g. accelerations, decelerations, changes of direction etc) once deemed valid and reliable (Akenhead et al., 2014), would therefore be required (across teams from within and between different domestic leagues and countries) to more accurately prescribe CHO guidelines for elite level soccer players.

Similar to the one game week schedule, there were also observed elements of training periodisation in the two game week whereby total distance and average speed were greatest on day 4 (5493 ± 421 m; 70.8 ± 5.4 m/min) compared with day 5 (4395 ± 261 m; 70.0 ± 3.8 m/min) and day 6 (2470 ± 184 m; 41.0 ± 2.9 m/min). Given the requirement to recover from the initial game within this week, training load was also lowest on day 3 i.e. 48 hours post-game one (1453 ± 65 m; 63.0 ± 2.0 m/min). Similar to the one game week, typical training intensity during this micro-cycle was relatively comparable where the majority of time was spent in low-to-moderate intensity zones (see Table 4.2.).

Due to the requirement to compete in two games per week, the total weekly accumulated distance and duration of activity was higher than the one game week schedule and also included significantly more time spent in the high-intensity zones. The duration of activity was also higher in the two game week versus the three game week, likely due to completion of an additional two training sessions where the focus is on recovery from match 1 and also the physical, technical and tactical preparation for match 2. In contrast, such training goals have to be combined into fewer sessions in the three game week where recovery tends to take priority. When taken together, it is likely that the concept of CHO periodisation during training days may still be applicable in this 2 game week schedule as long as high CHO intake (e.g. 6-10 $g.kg^{-1}$ body mass) is achieved on the day before match day, during match day and the day after match day.

In contrast to the one and two game week schedules, training frequency in the three game week schedule was limited to two sessions. Given the obvious focus of these sessions (i.e. recovery and tactical sessions), markers of training intensity and total distance were similar to that observed in the training sessions occurring on the day preceding match day in both the one and two game week schedules. However, due to competing in three games in the seven day period, the total accumulative distance covered was greater compared with the one game week. Moreover, due to the high intensity nature of matches, time spent in high-intensity speed zones was greater in the three game week compared with both the one and two game week schedule. Given the well documented role of muscle glycogen in fuelling match play (Krustrup et al., 2006) and also the difficulty of replenishing muscle glycogen stores in the 48-72 h post-game period (Krustrup et al., 2011; Gunnarsson et al., 2013), such data therefore clearly highlights the role of high daily CHO availability during this specific micro-cycle.

This type of weekly scenario is extremely common for those teams who are competing in any European competitions and often compete in midweek games as well as their own league games at the weekends. Games played at this frequency over a short period of time potentially results in residual fatigue and underperformance due to insufficient time for physical recovery whilst also increasing the propensity of injury (Dupont et al., 2010). However, it is possible that playing games this frequently and undergoing an adequate recovery, players could actually use the game stimulus to maintain or even improve aerobic capacity. If this pattern of loading is prevalent throughout the season, then the need for higher CHO intakes should be increased accordingly.

Although this is the first report of training and match load during three different game schedules, the data are not without limitations that are largely a reflection of currently available technology and the practical demands of data collection in an elite football setting. The ecological validity of this study would however be considered high. Firstly, the simultaneous use of both GPS and Prozone® to quantify training and match demands, respectively, has obvious implications for the comparability of data between systems (Harley et al., 2011; Buchheit et al., 2014b). Nevertheless, this is the approach to monitoring that is commonly employed by sports scientists in the elite soccer environment and is currently a difficult methodological issue to overcome. Secondly, the use of GPS *per se* to make inferences on EE during training is also limited as methodological issues associated with the technology (e.g. sampling frequency; Aughey, 2011) are likely to underestimate the real energy requirements. Third, sessions were clipped to encompass the entire training session (as opposed to provide drill by drill breakdowns) and this may have led to a lower overall average training intensity. Nevertheless, this was initially deemed this valid given that it is the total training time data that are typically used to provide coaches with training reports. Future studies providing drill-by-drill characteristics would now appear warranted.

This study is also reflective of one team only (albeit reflective of a top English Premier League team) and hence may not be representative of the customary training demands of other domestic teams (Gaudino et al., 2013) or from other countries (Owen et al., 2014) that may be influenced by different managerial and coaching philosophies. For example, as players of a lower standard generally undergo higher load during match play (Bradley et al., 2013) there is likely to be a greater total requirement for CHO. Finally, although the chosen weekly scenarios were on the basis of the number of players who completed all games and training sessions, it is worth noting that the pattern of loading is likely to be different during different phases of the season due to factors such as residual fatigue. As such, there is a definitive need to more accurately quantify daily EE (that would also take in account EE during any resistance training sessions) and EI so as to more accurately inform nutritional periodisation strategies.

4.6. CONCLUSION

In summary, this study quantified for the first time, the daily training and accumulative weekly load (reflective of both training and match play) in professional soccer players during a one, two and three game per week schedule. Importantly, it is reported that customary training loads (e.g. total distance ranging from 3-5 km per day) are likely lower than other athletes in team (e.g. Australian football) and endurance sports, as well as observing evidence of periodisation of training load between days within each microcylce (i.e. reduction of total distance and intensity when tapering for match day). When taken together, these data support the concept of CHO periodisation whereby CHO is altered in accordance with the daily training load as well as the requirement to fuel and recover from match play. This concept is especially relevant given that muscle glycogen is the predominant energy source for soccer match play but also that consistently high levels of muscle glycogen may attenuate training adaptations. Future studies providing more detailed measures of EE and additional indicators of training load as well as players' habitual EI are now required to more accurately prescribe CHO guidelines for elite level soccer players.

CHAPTER 5

QUANTIFICATION OF SEASONAL LONG PHYSICAL LOAD IN SOCCER PLAYERS WITH DIFFERENT STARTING STATUS FROM THE ENGLISH PREMIER LEAGUE: IMPLICATIONS FOR MAINTAINING SQUAD PHYSICAL FITNESS

Having quantified the physical loading in three common micro-cycles in Study 1, the important of participation in match play in contributing to the overall weekly load was readily apparent. Accordingly, the aim of this chapter was to quantify the differences in seasonal long workload in players of different starting status from an English Premier League club. The full manuscript was published in the International Journal of Sports Physiology and Performance August 2016.

5.1. ABSTRACT

Soccer players are likely to receive different physical loading patterns depending on whether they regularly start matches or not. In an attempt to quantify the accumulative training and match load during an annual season in English Premier League soccer players classified as starters (n=8, started ≥60% of games), fringe players (n=7, started 30-60% of games) and non-starters (n=4, started <30%% of games). Players were monitored during all training sessions and games completed in the 2013-2014 season with load quantified using GPS and ProZone® technology, respectively. When including both training and matches, total duration of activity (10678 ± 916, 9955 ± 947, 10136 ± 847 min; P=0.50) and distance covered (816.2 ± 92.5, 733.8 ± 99.4, 691.2 ± 71.5 km; P=0.16) was not different between starters, fringe and non-starters, respectively. However, starters completed more (all P<0.01) distance running at 14.4-19.8 km $\cdot$ h^{-1} (91.8 ± 16.3 v 58.0 ± 3.9 km; ES=2.5), high speed running at 19.9-25.1 km $\cdot$ h^{-1} (35.0 ± 8.2 v 18.6 ± 4.3 km; ES=2.3) and sprinting at >25.2 km $\cdot$ h^{-1} (11.2 ± 4.2, v 2.9 ± 1.2 km; ES=2.3) than non-starters. Additionally, starters also completed more sprinting (P<0.01. ES=2.0) than fringe players who accumulated 4.5 ± 1.8 km. Such differences in total high-intensity physical work done were reflective of differences in actual game time between playing groups as opposed to differences in high-intensity loading patterns during training sessions. It is concluded that unlike total seasonal volume of training (i.e. total distance and duration), seasonal high-intensity loading patterns are dependent on players' match starting status thereby having potential implications for training programme design.

Key Words: GPS, Prozone, high-intensity zones, training load

5.2. INTRODUCTION

Soccer match play is characterised by brief bouts of high-intensity linear and multidirectional activity interspersed with longer recovery periods of lower intensity (Varley & Aughey, 2013). Elite players typically cover 10-14 km in total distance per game (Dellal et al., 2011; Di Salvo et al., 2007; Bloomfield et al., 2007; Bangsbo et al., 2006; Fernandes et al., 2007) where both high intensity (speeds > 14.4 km $\cdot$ h^{-1}) and very high-intensity running distance (speeds > 19.8 km $\cdot$ h^{-1}) contribute ~25 and ~8% of the total distance covered, respectively (Rampinini et al., 2007; Bradley et al., 2009). Top-class soccer players also perform 150-250 intense actions per game (Mohr et al., 2003) and complete a very high-intensity run approximately every 72 s (Bradley et al., 2009).

In order to successfully meet these demands, the physical preparation of elite players has become an indispensable part of the professional game, with high fitness levels required to cope with the ever-increasing demands of match play (Iaia et al., 2009; Barnes et al., 2014). Nonetheless, despite nearly four decades of research examining the physical demands of soccer match play (Reilly & Thomas, 1976), the quantification of the customary training loads completed by elite professional soccer players are not currently well known. For players of the English Premier League, such reports are limited to a 4-week winter fixture schedule (Morgans et al., 2014b), a 10-week period (Gaudino et al., 2013), seasonal long analysis (Malone et al., 2015) and most recently, an examination of the effects of match frequency in a weekly micro-cycle (Anderson et al., 2015; Chapter 4). It is noteworthy that the absolute physical loads of total distance (e.g. < 7 km), high intensity distance (e.g. < 600 m) and very high intensity distance (e.g. < 400 m) collectively reported in these studies do not near recreate those completed in matches. As such, although the typical current training practices of professional players may be sufficient in order to promote recovery and readiness for the next game (thus reducing risk of over-training and injury), it could also be suggested that it is the participation in match play itself that is the most appropriate stimulus for preparing players for the physical demands of match play. This point is especially relevant considering previous evidence demonstrating significant positive correlations between individual in season playing time and aspects of physical performance including sprint performance and muscle strength (Silva et al., 2011).

Such differences between match and training load can be particularly challenging for fitness and conditioning staff given that players in a first team squad are likely to receive different loading patterns, depending on whether they regularly start matches or not. In this way, discrepancies in physical loads between players could lead to differences in important components of soccer-specific fitness which may subsequently present itself on match day when players not accustomed to match loads are now required to complete the habitual physical loads performed by regular starting players. The challenge of maintaining squad physical fitness is also technically difficult, given both organisational and traditional training practices inherent to professional soccer. For example, in the English Premier League, it is not permitted for players to train on the same pitch where the game was played for >15 minutes post-match. Furthermore, it is often common practice for the entire playing squad to be given 1-2 days of recovery following each game (consisting of complete inactivity or light recovery activities only), especially in those instances where the fixture schedule consists of the traditional Saturday-to-Saturday schedule (Anderson et al., 2015; Chapter 4).

With this in mind, the aim of the present study was to quantify the accumulative training and match load (hence total accumulative physical load) across an annual season in those players considered as regular starters, fringe players and non-starters. To this end, outfield players from the English Premier league were monitored (who competed in the 2013-2014 season) who were classified as starters (starting ≥60% of games), fringe players (starting 30-60% of games) and non-starters (starting <30% of games). It was hypothesised that both fringe and non-starting players would complete significantly less total physical load (especially in high-intensity zones) than starting players, thereby providing practical applications for the development of soccer-specific conditioning programs designed to maintain squad physical fitness.

5.3. METHODS

5.3.1. PARTICIPANTS

Nineteen professional outfield soccer players from an English Premier League team (mean ± SD: age 25 ± 4 years, body mass 79.5 ± 7.8 kg, height 180.4 ± 6.4 cm) took part in the study. When quantifying data from the entire "in-season analysis" there were 8 starters (mean ± SD: age 25 ±5 years, body mass 80.6 ± 8.3 kg, height 178.8 ± 6.3 cm), 7 fringe (mean ± SD: age 26 ± 4 years, body mass 79.7 ± 7.4 kg, height 181.0 ± 7.3 cm) and 4 non-starters (mean ± SD: age 23 ± 3 years, body mass 74.5 kg, height 181.5 ± 6.9 cm). Players with different position on the field were tested: 5 wide defenders, 4 central defenders, 6 central midfielders, 2 wide midfielders and 3 attackers. Long-term injuries were excluded from this study if they were absent for on field training for duration >4 weeks. The study was conducted according to the requirements of the Declaration of Helsinki and was approved by the university ethics committee of Liverpool John Moores University.

5.3.2. STUDY DESIGN

Training and match data were collected over a 39-week period during the 2013-2014 competitive season from August 2013 until May 2014. The team used for data collection competed in 3 official domestic competitions across the season. For the purposes of this current study, training sessions included for analysis consisted of all of the 'on pitch' training each player was scheduled to undertake. Sessions that were included in the analysis were team training sessions, individual training sessions, recovery sessions and rehabilitation training sessions. A total number of 181 team-training sessions (2182 individual), 159 rehab sessions (213 individual), 28 recovery sessions (179 individual), 43 competitive matches including substitute appearances (531 individual) and 12 non-competitive games including substitute appearances (33 individual) were observed during this investigation. All data reported are for outdoor field based sessions only. In the season of analysis, the players studied did not do any additional aerobic/ high-intensity conditioning in the gym or an indoor facility.

However, all players did complete 1-3 optional gym based sessions per week (typically consisting of 20-30 minute long sessions comprising upper and/or lower body strength based exercises). When expressed as ‘total time’ engaged in training activities (i.e. also inclusive of gym training) and games, the data presented in the present paper therefore represent 78±10, 79±6 and 86±7% of ‘total time’ for starters, fringe players and non-starters, respectively. This study did not influence or alter any session or game in any way nor did it influence the inclusion of players in training sessions and/or games. Training and match data collection for this study was carried out at the soccer club’s outdoor training pitches (Figure 3.1.) and both home (Figure 3.2.) and away grounds in the English Football League, respectively.

The season was analyzed both as a whole and in 5 different in-season periods consisting of 4x8 weeks (periods 1-4) and 1x7 week period (period 5). Players were split into 3 groups for the entire in season analysis and individually for each in season period. The 3 groups consisted of “starters”, “fringe” and “non-starters” and were split based on the percentage of games started for the entire in season (n=8, 7 and 4, respectively) and during the individual period 1 (n=8, 5 and 6, respectively), period 2 (n=9, 5 and 5, respectively), period 3 (n=6, 8 and 5, respectively), period 4 (n=8, 5 and 6, respectively) and period 5 (n=11, 2 and 6, respectively). Starting players started ≥60% competitive games, fringe players started 30-60% of games and non-starting players started <30% of games. The first day of data collection period began in the week commencing (Monday) of the first Premier League game (Saturday) and the last period ended after the final Premier League game. Data for the entire in season and each individual period was further divided into training and matches. As outlined previously, training consisted of all ‘on pitch’ training sessions that were organised and planned by the clubs coaches and staff and match data consisted of both competitive and non-competitive games. No data from training or games from when players were on International camps were collected.

5.3.3. QUANTIFICATION OF TRAINING AND MATCH LOAD

Training and match data were collected and analysed as described in section 3.4.

5.3.4. STATISTICAL ANALYSIS

All of the data are presented as mean ± standard deviation (SD). Data were analysed using between-group one-way ANOVAs for independent samples. When the F-test was significant ($p<0.05$), post-hoc pairwise comparisons were performed, in which the significance level was adjusted to 0.017 (Bonferroni correction). Cohen's d indices were calculated for all pairwise differences to determine an effect size (ES). The absolute ES value was evaluated according to the following thresholds: < 0.2 = trivial, 0.2-0.6 = small, 0.7-1.2 = moderate, 1.3-2.0 = large, and > 2.0 = very large.

5.4. RESULTS

5.4.1. SEASONAL LONG COMPARISON OF "TOTAL" PHYSICAL LOAD

A comparison of seasonal physical load (inclusive of both training and matches) is presented in Table 5.1. Although there was no significant difference in total duration (P=0.502) and distance covered (P=0.164) between player categories, non-starters completed significantly less running (P=0.002; ES=2.5), high-speed running (P=0.004; ES=2.3) and sprinting (P=0.003; ES=2.3) than starters. Additionally, fringe players completed significantly less sprinting than starters (P=0.002; ES=2.0) though no differences were apparent in running (P=0.062) and high-speed running (P=0.038) between these groups.

Table 5.1. Total duration (minutes), total distance (km), running distance (km), high-speed running distance (km) and sprinting distance (km) covered across the entire in-season period, as inclusive of both training and matches.

	Starters	Fringe	Non-Starters
Duration	10678 ± 916	9955 ± 947	10136 ± 874
Total Distance	816.2 ± 92.5	733.8 ± 99.4	691.2 ± 71.6
Running	91.8 ± 16.3	72.9 ± 19.8	58.0 ± 3.9*
High-Speed Running	35.0 ± 8.2	24.9 ± 8.8	18.6 ± 4.3*
Sprinting	11.2 ± 4.2	4.5 ± 1.8*	2.9 ± 1.2*

* denotes difference from starters, P<0.05 (Bonferroni corrected).

5.4.2. SEASONAL LONG COMPARISON OF TOTAL "TRAINING" AND "MATCH" PHYSICAL LOAD

A comparison of seasonal long training and match load is presented in Figure 5.1.A and B (for duration and total distance). In relation to matches, both fringe and non-starters completed less duration of activity (both $P<0.01$; ES=2.7 and 5.7, respectively) and total distance (both $P<0.01$; ES=5.4 and 2.5, respectively) compared with starters. Additionally, non-starters also completed less duration ($P=0.001$; ES=0.7) and total distance than fringe players ($P=0.001$; ES=0.7). In relation to training, differences were only apparent between non-starters and starters where non-starters spent longer time training ($P=0.003$; ES=2.4) and covered greater total distance ($P=0.003$; ES=2.3).

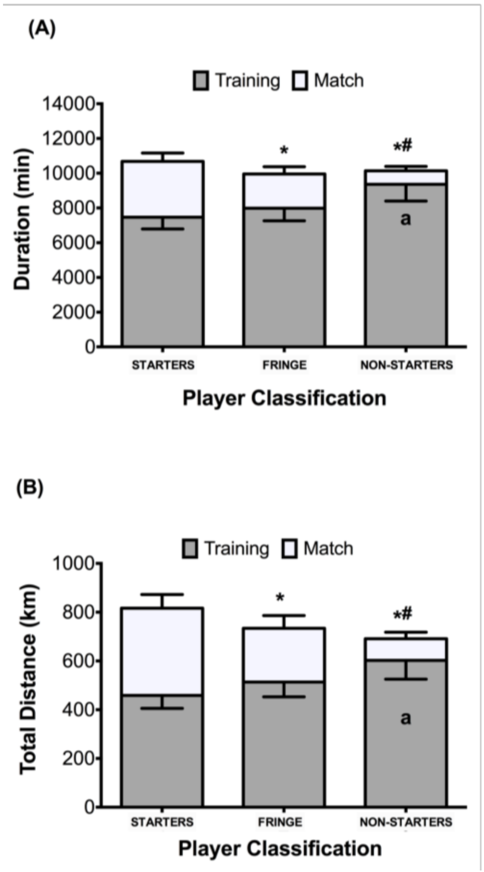


Figure 5.1. Accumulative season long A) duration and B) total distance in both training and matches. Shaded bars = training and open bars = matches. * denotes difference to starters (matches), # denotes difference to fringe players (matches), a denotes difference to starters (training), $P<0.05$ (Bonferroni corrected).

5.4.3. SEASONAL LONG COMPARISON OF "TRAINING" AND "MATCH" PHYSICAL LOAD IN HIGH-INTENSITY SPEED ZONES

Seasonal long distance covered in running, high-speed running and sprinting in both training and matches is displayed in Figure 5.2.A-C. In relation to matches, both fringe and non-starters completed significantly less distance in running (both $P<0.01$; ES=1.7 and 4.0, respectively), high-speed running (both $P<0.01$; ES=2.0 and 3.4, respectively) and sprinting (both $P<0.01$; ES=2.2 and 2.6, respectively) compared with starters. In addition, fringe players covered significantly more distance in running than non-starters (P=0.008; ES=0.7). However, no differences were apparent between fringe and non-starters for high-speed running and sprinting (P=0.026 and 0.045; ES=0.7 and 0.5, respectively). In contrast to match load, no differences were observed between groups for distance completed in running, high-speed running and sprinting during training (P=0.297, 0.658 and 0.802, respectively).

Table 5.2. Total duration (minutes), total distance (km), running distance (km), high-speed running distance (km) and sprinting distance (km) within 5 specific in-season periods

Variable	Period	Starters	Fringe	Non-Starters
Duration	**1**	2029 ± 459	1780 ± 565	1784 ± 454
	2	1976 ± 354	1971 ± 345	1900 ± 450
	3	2225 ± 243	1934 ± 237	2019 ± 360
	4	2361 ± 104	2150 ± 225	1931 ± 321*
	5	2174 ± 187	2174 ± 187	1758 ± 187*
Total Distance	**1**	158.3 ± 37.7	125.3 ± 35.1	124.1 ± 28.9
	2	152.3 ± 29.1	144.7 ± 33.1	142.8 ± 38.8
	3	177.1 ± 22.2	147.5 ± 23.2	137.3 ± 20.2*
	4	184.9 ± 13.3	159.9 ± 25.5	132.3 ± 21.2*
	5	160.9 ± 17.1	136.6 ± 35.7	107.2 ± 12.2*
Running	**1**	17.9 ± 4.5	13.1 ± 2.2	12.6 ± 1.1*
	2	16.3 ± 4.4	14.4 ± 5.8	13.6 ± 4.0
	3	20.5 ± 4.2	15.5 ± 4.9	12.5 ± 2.4*
	4	21.4 ± 3.8	15.7 ± 5.0	10.3 ± 1.9*
	5	16.7 ± 3.3	12.5 ± 6.0	6.9 ± 1.3*
High-Speed Running	**1**	7.4 ± 2.7	5.7 ± 0.6	5.2 ± 1.0
	2	6.0 ± 2.5	5.1 ± 2.8	5.3 ± 1.9
	3	8.3 ± 2.5	5.1 ± 1.9	4.0 ± 1.2*
	4	7.4 ± 1.7	5.2 ± 2.5	3.3 ± 1.5*
	5	5.5 ± 1.6	3.4 ± 2.3	1.5 ± 0.5*
Sprinting	**1**	2.4 ± 1.2	1.3 ± 0.3	1.0 ± 1.0
	2	1.6 ± 0.7	0.7 ± 0.3	0.5 ± 0.4*
	3	3.1 ± 1.3	1.3 ± 0.4*	0.7 ± 0.3*
	4	2.5 ± 1.0	1.1 ± 0.6*	0.3 ± 0.1*$^{\#}$
	5	1.8 ± 0.8	0.6 ± 0.5	0.2 ± 0.1*

* denotes difference to starters, $^{\#}$ denotes difference to fringe players, P<0.05 (Bonferroni corrected).

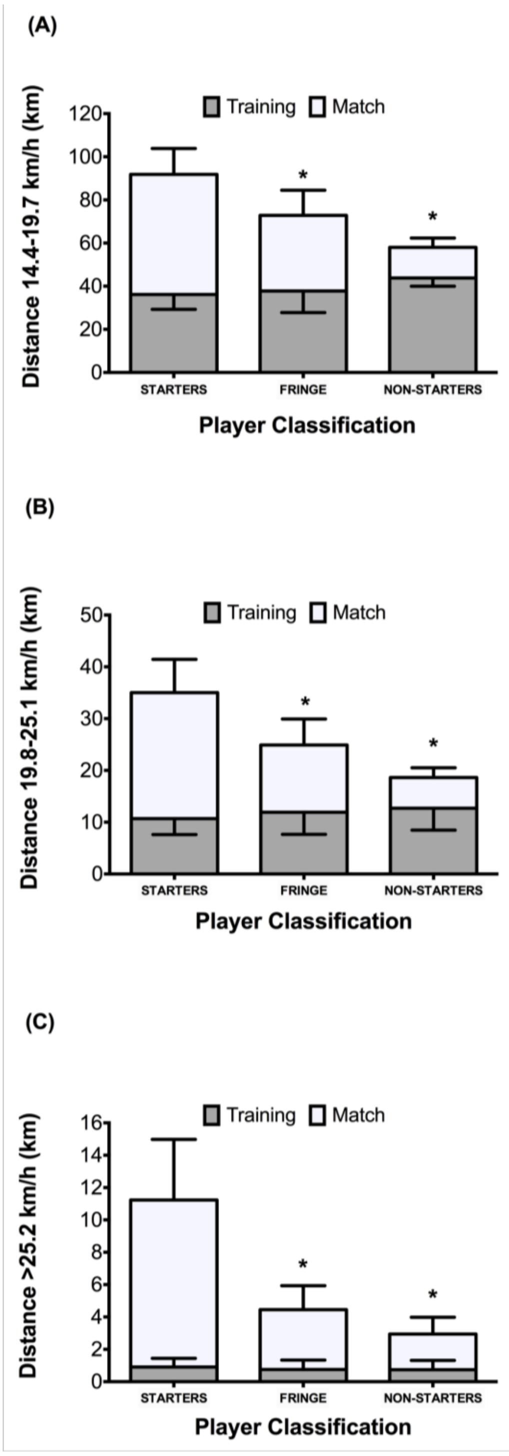


Figure 5.2. Accumulative season long A) running distance, B) high-speed running distance and C) sprinting distance in both training and matches. Shaded bars = training and open bars = matches. * denotes difference to starters, P<0.05 (Bonferroni corrected).

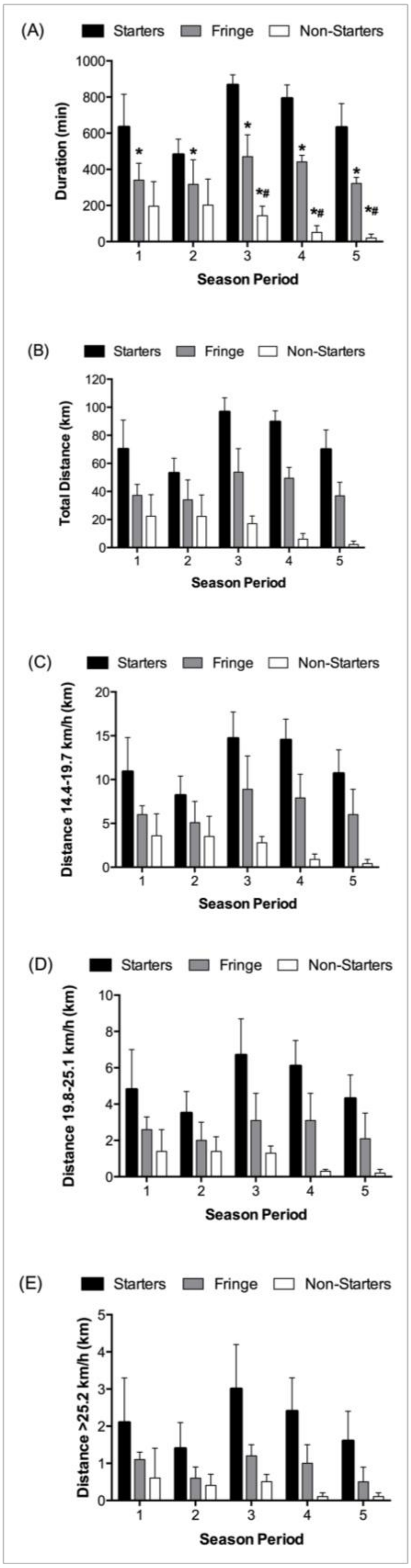


Figure 5.3. Within period accumulative A) duration, B) total distance, C) running distance, D) high-speed running distance and E) sprinting distance in match per se. * denotes difference to starters, # denotes difference to fringe players, P<0.05 (Bonferroni corrected).

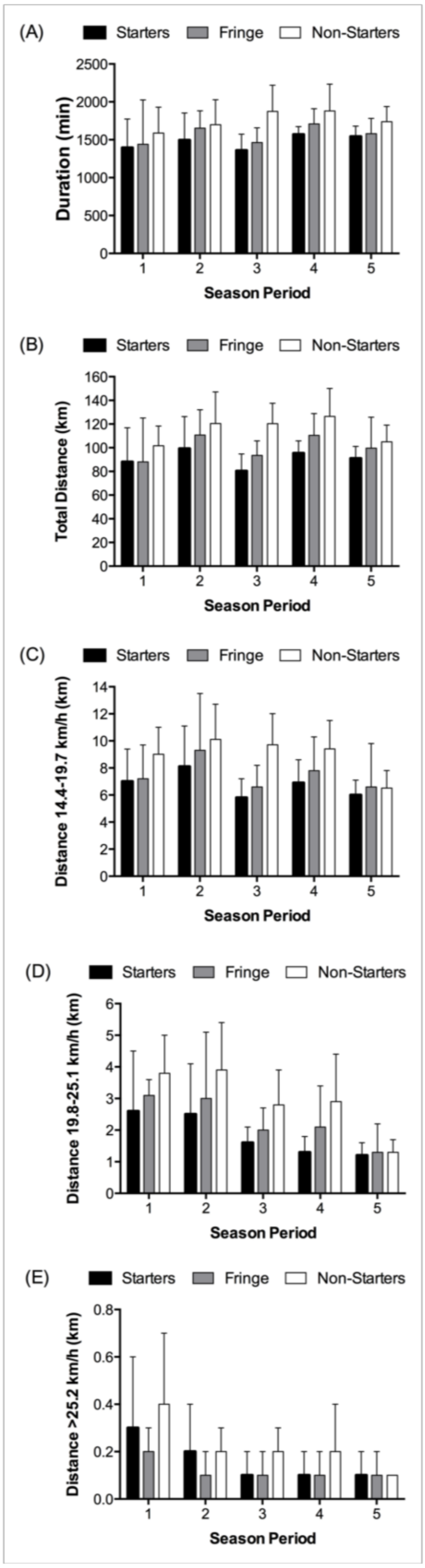


Figure 5.4. Within period accumulative A) duration, B) total distance, C) running distance, D) high-speed running distance and E) sprinting distance in training per se. * denotes difference to starters, # denotes difference to fringe players, P<0.05 (Bonferroni corrected).

5.4.4. COMPARISON OF "TOTAL" PHYSICAL LOAD WITHIN SPECIFIC IN-SEASON PERIODS

Total duration, total distance and distance completed in high-intensity speed zones within 5 in-season periods of the season are presented in Table 5.2. For duration of total activity, significant differences were only observed in periods 4 ($P=0.004$; ES=1.9) and 5 ($P=0.001$; ES=2.2) where non-starters completed less total duration of activity than starters, respectively. Similarly, non-starters also completed less total distance than starters in periods 3-5 (all $P<0.01$, respectively; ES=1.9, 3.1 and 3.4, respectively), less running in periods 1, 3, 4 and 5 (all $P<0.01$, respectively; ES=1.0, 2.3, 3.6 and 3.6, respectively), less high-speed running in periods 3-5 (all $P<0.01$, respectively; ES=2.1, 2.6 and 3.0, respectively) and less sprinting in periods 2-5 (all $P<0.01$, respectively; ES=1.6, 2.5, 3.0 and 2.5, respectively). Furthermore, starters completed more sprinting distance than fringe in periods 3 and 4 (both $P<0.01$, respectively; ES=2.2 and 1.6, respectively) but fringe only differed from non-starters in period 4 only where they completed more sprinting ($P=0.006$; ES=1.2).

5.4.5. COMPARISON OF "TRAINING" AND "MATCH" PHYSICAL LOAD WITHIN IN-SEASON PERIODS

Duration of activity, total distance, running, high-speed running and sprinting in matches are displayed in Figure 5.3.A-E. As expected, in periods 1-5, starters had higher duration than both non-starters (all $P<0.01$; ES=2.7, 2.6, 13.2, 11.9 and 5.6, respectively) and fringe (all $P<0.01$; ES=1.9, 1.6, 4.0, 5.5 and 2.5, respectively) whilst fringe players also exhibited higher durations than non-starters in periods 3-5 (all $P<0.01$; ES=0.9, 1.3 and 2.3). Similarly, starters covered higher total distances in periods 1-5 than both non-starters (all $P<0.01$; ES=2.6, 2.5, 9.5, 12.8 and 5.9, respectively) and fringe (all $P<0.01$; ES=1.9, 1.6, 3.0, 5.1 and 2.4, respectively) and fringe players covered higher total distances than non-starters in periods 3-5 (all $P<0.01$; ES=0.9, 1.3 and 2.3, respectively).

In relation to specific speed zones, starters completed more running in periods 1-5 than non-starters (all $P<0.01$; ES=2.2, 2.1, 5.1, 7.2 and 4.7, respectively), more high-speed running in periods 1-5 (all P<0.01; ES=1.8, 1.9, 3.5, 5.5 and 3.8) and more sprinting in periods 2-5 (all P<0.01; ES=1.7, 2.8, 3.2 and 2.5). Moreover, starters completed more running than fringe players in periods 3 (P=0.009; ES=1.7) and 4 (P=0.001; ES=2.6), more high-speed running in periods 3 (P=0.003; ES=2.0) and 4 (P=0.004; ES=2.1) and more sprinting in periods 3 (P=0.001; ES=2.2) and 4 (P=0.012; ES=1.7). Fringe players also covered more running distance in periods 3-5 (all P<0.01; ES=0.9, 1.3 and 2.3, respectively), more high-speed running in periods 4 (P=0.002; ES=1.3) and 5 (P=0.008; ES=2.2) and more sprinting in period 4 (P=0.003; ES=1.3) than non-starters.

Duration of activity, total distance, running, high-speed running and sprinting in training are displayed in Figure 5.4.A-E. In contrast to matches, total duration of activity was only different in period 3 (P=0.014; ES=1.8) where non-starters trained for longer durations than starters. In addition, starters completed less total distance in periods 3 and 4 compared to non-starters (both P<0.01; ES=2.5, 1.8, respectively) and non-starters also covered more total distance in period 3 than fringe players (P=0.007; ES=0.4). Non-starters also covered more running than starters and fringe players in period 3 (both P<0.01; ES=2.1 and 0.6, respectively) and more high-speed running than starters in period 4 (P=0.015; ES=1.5). Finally, no differences were apparent between groups for sprinting during periods 1-5 (P=0.506, 0.361, 0.605, 0.521 and 0.487).

5.5. DISCUSSION

The aim of the present study was to quantify the accumulative training and match load (and total accumulative physical load) during an annual season in those players considered as regular starters, fringe players and non-starters. Contrary to our hypothesis, starting status had no effect on the apparent total volume completed, as reflected by total duration of activity and total distance covered during the season. Perhaps more important, however, was the observation of significant differences in the pattern of activity completed within specific high-intensity speed zones. In this regard, starters generally completed more distance in running, high-speed running and sprinting zones than both fringe and non-starting players. This effect was largely due to differences in game time between groups as opposed to differences in training loading patterns. Given the role of training intensity in promoting soccer-specific fitness (Iaia et al., 2009; Bangsbo, 2008; Dupont et al., 2004; Wells et al., 2014), our data therefore suggest that the training practices of those players not deemed to be receiving appropriate game time should be altered to include more emphasis on recreating the high-intensity demands of match play, so as to potentially maintain overall squad fitness, game readiness and reduce injury risk.

To the authors' knowledge, this is the first study to report seasonal long physical loads completed by elite professional soccer players. In the seasonal long accumulation analysis, there was no evidence observed of starting status affecting total duration of activity or total distance covered across the entire in-season period (see Table 5.1.). For example, total duration and total distance were similar in starters, fringe and non-starters. These distances are substantially higher (e.g. approximately 400 km) than that observed in a competitive in-season in other team sports such as Australian Football (Colby et al., 2014) likely due to shorter seasons in the latter i.e. 22 weeks (18 weeks in the study) versus 39 weeks in the English Premier League.

Although no differences were observed in the seasonal long profile between groups (i.e. duration and total distance covered), the proportion of this volume made up from training and game is, as expected, significantly different between groups. For example, in relation to training, starters displayed lower duration and total distances than non-starters but not fringe players. This fact is, of course, due to the fact that starting players engage in "recovery" training activities and days after games as opposed to traditional training sessions (Morgans et al., 2014b; Anderson et al., 2015). When quantifying match load, however, starters displayed higher duration and total distance than both fringe players and non-starters. Given the obvious difference between the physical and physiological demands between training and matches (Morgans et al., 2014b; Anderson et al., 2015), such data could potentially suggest that the long-term physiological adaptations arising within these playing groups are likely very different. This point is especially apparent when considering the large discrepancy between intensity specific physical loads between groups. For example, starters covered higher distances in running and high-speed running speed zones, respectively, when compared with non-starters, but not fringe players (see Table 5.1.). In addition, seasonal long distance covered whilst sprinting was also higher in starters compared to both fringe players and non-starters. As such, these data demonstrate that although players are able to maintain similar volume across the in-season period, distance covered in high-intensity zones is considerably greater in starters.

The differences in high-intensity loading patterns between groups is also especially relevant when considering that such differences were not due to alterations in training loads but rather, merely due to starters engaging in the high-intensity activity associated with match play. Indeed, there were no differences in running, high-speed running and sprinting in training *per se* between starters, fringe players and non-starters. In contrast, starters displayed higher distance in matches when running, high-speed running and sprinting compared to fringe and non-starters (see Figure 5.2.A-C). Such data clearly highlight that it is the participation in match play per se which represents the most appropriate opportunity to achieve high-intensity loading patterns. The practical implications of such discrepancies are important for designing training programmes to maintain overall squad physical fitness and game readiness. Indeed, the distances covered at these speeds during games display strong associations to physical capacity (Krustrup et al., 2003; Krustrup et al., 2005) and thus, players not consistently exposed to such stimuli during the season may eventually display de-training effects when compared to that displayed in the pre-season period (Iaia et al., 2009; Silva et al., 2011). Indeed, completion of high-intensity activity (even at the expense of total physical load done) is both sufficient and necessary to activate the molecular pathways that regulate skeletal muscle adaptations related to both aerobic (Egan et al., 2010; Gillen et al., 2014) and anaerobic (Iaia et al., 2008) performance. Additionally, when those players classified as fringe or non-starters are then required to start games, a potential for injury also exists due to the necessity to complete uncustomary loading patterns (Gabbett, 2004).

In addition to the seasonal long physical loads, training and match load were also quantified within 5 discrete discrete periods of the in-season period. In this analysis, variations in physical load between groups were especially evident in periods 3, 4 and 5, an effect that was especially apparent between starters and both non-starters and fringe players for total duration, total distance and total zone 6 activity (i.e. sprinting). Similar to the seasonal long analysis, these differences between groups were also largely reflective of differences in game time as opposed to training time. Such differences in loading within specific in-season periods are likely due to tactical and technical differences associated with specific fixture schedules. For example, in the present study, period 3 was the winter fixture schedule (Morgans et al., 2014b) whereas periods 4 and 5 were reflective of a period where the team under investigation was challenging for domestic honors. In all of these periods, the management and coaching staff displayed little squad rotation policies and hence, differences in loading inevitably ensued.

Despite the novelty and practical application of the current study, our data are not without limitations, largely a reflection of currently available technology and the practical demands of data collection in an elite football setting. Firstly, the simultaneous use of both GPS and Prozone® to quantify training and competitive match demands, respectively, has obvious implications for the comparability of data between systems (Harley et al., 2011; Buchheit et al., 2014). Nevertheless, during the chosen season of study, it was against FIFA rules to wear GPS in competitive matches. Whilst it is now within the rules to wear GPS in competitive games, it is still not common policy due to managers' preferences, players' comfort issues and poor signal strength due to the roofing in many stadiums in the English Premier League. Secondly, data from games or training from International camps were not reported given that the current research team or clubs tactical and coaching staff did not control the loads of these practices. Finally, this study is only reflective of one team (albeit reflective of a top English Premier League team) and hence may not be representative of the customary training and match demands of other domestic teams or teams from other countries. When taken together, the simultaneous use of GPS in training and games, quantification of load in additional settings and the use of wider based samples all represent fruitful areas for future research.

Given that there were distinct differences in high-intensity distance completed throughout the season, our data have obvious practical implications for training programme design. In this regard, data suggest that players classified as fringe and non-starters should engage in additional high-intensity training practices and/or complete relevant time in non-competitive friendlies and U21 games in an attempt to recreate the high-intensity physical load typically observed in competitive first team games. This point is especially important given the relevance and importance of high-intensity activity in both building and maintaining aspects of soccer specific fitness. Furthermore, our observation of more marked differences in periods 3, 4 and 5 of the season also suggest that specific attention should be given to those periods of the season when tactical choices dictate low-squad rotation policies. Future studies should now correlate changes in physical load during the season to seasonal variation in soccer-specific fitness components as well as introducing soccer-specific training interventions at the relevant in-season periods (e.g. Iaia et al., 2015).

5.6. CONCLUSION

In summary, accumulative training and match load (and total accumulative physical load) were quantified during an annual season in-season in those players considered as regular starters, fringe players and non-starters for the first time. Importantly, although it is reported that total duration of activity and total distance covered was not different between playing groups, there were observed differences in that starters generally completed more time in high-intensity zones than fringe and non-starters players. Our data demonstrate the obvious importance of participation in game time for completing such high-intensity physical load. Such data suggest that the training practices of these latter groups should potentially be manipulated in order to induce comparable seasonal workloads.

CHAPTER 6

ENERGY INTAKE AND EXPENDITURE OF PROFESSIONAL SOCCER PLAYERS OF THE ENGLISH PREMIER LEAGUE: EVIDENCE OF CARBOHYDRATE PERIODISATION AND 'SKEWING' OF MEAL DISTRIBUTION

Having quantified the physical loading patterns in Study 1 and 2, the aim of this chapter was to subsequently examine the energy expenditure and energy intake of soccer players from the English Premier League over an in-season micro-cycle. This chapter was published as two companion papers in the International Journal of Sports Nutrition and Exercise Metabolism in June and July 2017.

6.1. ABSTRACT

In an attempt to better inform the energy requirements of elite soccer players, EI and EE was quantified in English Premier League soccer players (n=6) during a 7-day in-season period consisting of two match days (MD) and five training days (TD), as assessed using food diaries (supported by the RFPM and 24 h recalls) and the DLW method. Although mean daily EI (3186 ± 367 kcals) was not different from ($P>0.05$) daily EE (3566 ± 585 kcals), EI was greater on ($P<0.05$) MD (3789 ± 577 kcal; 61.1 ± 12.5 $kcal.kg^{-1}$ LBM) compared with TD (2948 ± 686 kcal; 45.2 ± 12.2 $kcal.kg^{-1}$ LBM, respectively). Differences in EI were reflective of greater ($P<0.05$) daily CHO intake on MD (6.4 ± 2.2 $g.kg^{-1}$) compared with TD (4.2 ± 1.6 $g.kg^{-1}$). Exogenous CHO intake was also different ($P<0.01$) during training sessions (5.3 ± 10.3 $g.hr^{-1}$) versus matches (31.9 ± 21.0 $g.hr^{-1}$). In contrast, daily protein (205 ± 30 g, $P=0.29$) and fat intake (101 ± 20 g, $P=0.16$) did not display any evidence of daily periodisation. It was also observed that there was a skewed daily distribution of energy, CHO, protein and fat intake on TD such that parameters were typically greater in lunch and dinner compared with breakfast and snacks. Although players readily achieve current guidelines for daily protein and fat intake, a higher daily CHO intake (6-8 $g.kg^{-1}$) is recommended on the day prior to and in recovery from match play so as to promote muscle glycogen storage.

Keywords: glycogen, training load, soccer, GPS

6.2. INTRODUCTION

Despite four decades of research examining the physical demands of soccer match play (Reilly & Thomas, 1976; Bloomfield et al., 2007; Carling et al., 2008; Bush et al., 2015a; Bush et al., 2015b), the quantification of the customary training loads completed by elite professional soccer players have only recently been examined (Anderson et al., 2015; Anderson et al., 2016; Morgans et al., 2014; Gaudino et al., 2014; Malone et al., 2015). Importantly, such data suggest that training loads do not near recreate those experienced in match play in terms of total distance (e.g. <7 km v ~10-12 km) high speed running distance (e.g. <300 m v ~1000 m), sprint distance (e.g. <150 m v >300 m) and average speed (e.g. <80 m/min v ~100-120 m/min). Daily training load during the weekly micro-cycle also displays evidence of periodisation, the pattern of which appears dependent on proximity to the game itself (Anderson et al., 2015) as well as the number of games scheduled (Morgans et al., 2014; Anderson et al., 2015).

Given the apparent daily fluctuations in training load, it follows that EE may vary accordingly and hence, EI could also be adjusted to account for the goals of that particular day. Indeed, the concept of "fuelling for the work required" has recently been suggested as a practical framework for which to apply nutritional periodisation strategies to elite athletes (Impey et al., 2016). In this regard, such strategies are intended to concomitantly promote components of training adaptation (e.g. activation of regulatory cell signaling pathways) but yet, also ensure adequate CHO (and energy) availability to promote competitive performance, reduce injury risk and aid recovery (Burke et al., 2011; Chamari et al., 2012; Burke et al., 2006). Despite such theoretical rationale, however, it is currently difficult to prescribe accurate nutritional guidelines for professional soccer players owing to a lack of study in the modern professional adult player (Ebine et al., 2002; Maughan, 1997; Bettonviel et al., 2016). Furthermore, recent inferences on contemporary fuelling guidelines for soccer players have been suggested on the basis of quantifying training load using GPS *per se* (Anderson et al., 2015), as opposed to simultaneous estimations of EI and direct measurement of EE.

With this in mind, the aim of the present study was to therefore simultaneously quantify EI, EE, training load and match load in professional soccer players. To this end, a cohort of professional players from the English Premier League was studied during a 7-day in season period in which two match days (MD) and five training days (TD) were completed. Self reported EI and direct measurement of EE was assessed using food diaries (supported by RFPM and 24 h diet recalls) and the DLW method, respectively.

6.3. METHODS

6.3.1. PARTICIPANTS

Six male professional soccer players (who have all played International standard) from an English Premier League first team squad (mean ± SD; age 27 ± 3 years, body mass 80.5 ± 8.7 kg, height 180 ± 7 cm, body fat 11.9 ± 1.2 %, fat mass 9.2 ± 1.6 kg, lean mass 65.0 ± 6.7 kg) volunteered to take part in the study. Players with different positions on the field took part in the study and included 1 wide defender, 1 central defender, 2 central midfielders (1 defending and 1 attacking), 1 wide midfielder and 1 center forward. All players remained injury free for the duration of the study. The study was conducted according to the Declaration of Helsinki and was approved by the University Ethics Committee of Liverpool John Moores University.

6.3.2. STUDY DESIGN

Data collection was conducted during the English Premier League 2015-2016 in-season across the months of November and December. An overview of the schedule prior to, during and post testing period can be found in table 4.1. Players continued with their normal in-season training that was prescribed by the club's coaching staff and were available to perform in two competitive games on days 2 and 5 during data collection. The last competitive game where players were able to take part in was 3 days prior to the commencement of data collection. During data collection, game 1 kicked off at 20:05 hours and game 2 kicked off at 16:15 hours, both being home fixtures in European and domestic league competitions, respectively. The next competitive game players were due to take part in was the day after the study concluded (i.e. Day 8). Before the study commenced all players underwent a whole body fan beam Duel-energy X-ray absorptiometry (DXA) measurement scan (Hologic QDR Series, Discovery A, Bedford, MA, USA) in order to obtain body composition, in accordance with the procedures described in section 3.3.

Table 6.1. Overview of the schedule prior to, during and post testing period

Day								
-1	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**+1**
Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday
Administer DLW solution	PM Training	AM Training PM Game (20:05)	AM Recovery + Training	PM Training	PM Game (16:15)	Off	PM Training PM Travel	AM Training PM Game (20:00)

6.3.3. QUANTIFICATION OF TRAINING AND MATCH LOAD

Training and match data were collected and analysed as described in section 3.4.

6.3.4. MEASUREMENT OF ENERGY EXPENDITURE USING DOUBLY LABELED WATER

Energy expenditure measurements were collected, stored and analysed using methods described in section 3.5.

6.3.5. ASSESSMENT OF TOTAL DIETARY INTAKE

Energy and macronutrient intakes were assessed and analysed using methods described in section 3.6. In addition, an assessment of inter-researcher reliability that was carried out by researchers is described in section 3.7.

6.3.6. STATISTICAL ANALYSIS

All data are presented as the mean ± standard deviation (SD). Training load data are shown for descriptive purposes only. Daily energy and macronutrient intake were analysed using one-way repeated measures ANOVAs. Meal distribution data was analysed using linear mixed models with meal as the fixed factor. A random intercept was set for each individual player. When there was a significant ($P < 0.05$) effect of the fixed factor, Tukey post-hoc pairwise comparisons were performed to identify which categories of the factor differed. This whole analysis was performed separately for training and match days. After the normal distribution of differences between data pairs was verified with Shapiro-Wilk tests ($P>0.05$ for all variables), paired Student's t tests (with statistical significance set at $P<0.05$) were then used to assess: the differences between energy and macronutrient intakes during match day one vs. match day two for any meal**,** the differences between the average daily EI and EE, the difference between CHO intake during training and matches, the difference between EI and CHO intake on match days vs. training days, and changes in body mass from before to after the study period. In all the analyses, statistical significance was set at $P<0.05$. The statistical analysis was carried out with R, version 3.3.1.

6.4. RESULTS

6.4.1. QUANTIFICATION OF DAILY AND ACCUMULATIVE WEEKLY LOAD

An overview of the individual daily training and match load and the accumulative weekly load is presented in Tables 6.1. and 6.2., respectively.

6.4.2. QUANTIFICATION OF DAILY ENERGY AND MACRONUTRIENT INTAKE

A comparison of daily energy and macronutrient intake is presented in Figure 6.1. Daily absolute and relative EI and CHO intake was significantly different across the 7-day period (all $P<0.05$). Specifically, players reported greater absolute and relative EI on day 2 (i.e. match day 1) compared with days 1 (both $P<0.05$) and 3 (both $P<0.05$). On day 5 (i.e. match day 2), players reported higher absolute and relative EI compared with days 1, 3, 4 and 6 (all $P<0.05$).

Additionally, players reported higher absolute and relative EI on day 7 compared with day 4 (both $P<0.05$) as well as higher absolute EI on day 5 compared to day 2 ($P=0.03$).

In relation to CHO intake, both absolute (all $P<0.01$) and relative intake (all $P<0.01$) was greater on day 2 compared to days 1, 3, 4 and 6. On day 5, both absolute and relative CHO intakes were higher than days 1 (both $P<0.02$) and 6 (both $P<0.02$). Absolute CHO intake was also higher on day 5 compared to day 4 ($P=0.05$), but did not achieve significance when expressed relatively ($P=0.06$).

In contrast to energy and CHO intake, there was no significant difference between days in the reported absolute protein ($P=0.29$), relative protein ($P=0.31$), absolute ($P=0.16$), and relative fat ($P=0.16$) intake.

Table 6.21. Training and match load variables (representative of average daily data in bold and individual data from players 1-6) completed in the 7-day testing period and the day following the testing period. Running distance = distance covered between 14.4-19.8 km · h^{-1}, high-speed running distance = distance covered between 19.8-25.2 km · h^{-1} and sprinting distance = distance covered >25.2 km · h^{-1}. Each player's position is shown in brackets. CF=Centre Forward, WD=Wide Defender, WM=Wide Midfielder, CDM=Central Defending Midfielder, CAM= Central Attacking Midfielder and CD=Central Defender.

	Day						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Duration (mins)	**52 ± 26**	**97 ± 42**	**17 ± 29**	**46 ± 0**	**76 ±39**	**8 ± 20**	**24 ± 0**
1	63	125	0	46	71	0	24
2	63	125	0	46	96	0	24
3	63	55	34	46	96	0	24
4	63	125	0	46	0	48	24
5	63	125	0	46	96	0	24
6	0	32	68	46	96	0	24
Total Distance (m)	**2865 ± 1494**	**9746 ± 5098**	**1036 ± 1758**	**2187 ± 355**	**8827 ± 4874**	**715 ± 1751**	**1061 ± 186**
1	3266	11631	0	1964	6981	0	1076
2	2679	11798	0	2162	10302	0	1022
3	3384	4562	1978	2727	12793	0	1092
4	3603	13513	0	1680	0	4290	737
5	4258	14730	0	2356	13153	0	1306
6	0	2243	4240	2234	9733	0	1131
Av. Speed (m/min)	**45.9 ± 23.8**	**100.7 ± 50.7**	**20.1 ± 31.2**	**47.8 ± 7.8**	**95.8 ± 49.7**	**14.9 ± 36.6**	**45.2± 5.0**
1	52.1	105.7	0	42.8	97.9	0	44.2
2	44.1	109.4	0	47.5	106.8	0	42.5
3	54.0	132.6	57.4	59.8	132.7	0	46.4
4	57.5	122.2	0	36.6	0	89.5	38.4
5	68	134.2	0	51.4	136.4	0	53.6
6	0	0	63.4	48.8	100.9	0	46.4
Running Distance (m)	**171 ± 122**	**1528 ± 1033**	**66 ± 114**	**91 ± 77**	**1483 ± 1061**	**67 ± 163**	**0**
1	186	1490	0	43	845	0	0
2	115	1754	0	108	1646	0	0
3	166	717	123	225	2606	0	0
4	184	2513	0	3	0	399	1
5	375	2686	0	107	2732	0	0
6	0	6	275	57	1067	0	0
High-Speed Running Distance (m)	**27 ± 25**	**637 ± 446**	**5 ± 8**	**24 ± 35**	**614 ± 421**	**15 ± 37**	**0**
1	31	739	0	8	473	0	0
2	21	906	0	36	665	0	0
3	4	317	12	90	1081	0	0
4	34	592	0	0	0	90	0
5	70	1270	0	8	1081	0	0
6	0	0	17	0	386	0	0
Sprinting Distance (m)	**2 ± 4**	**196 ± 146**	**0**	**5 ± 7**	**273 ± 167**	**0**	**0**
1	0	332	0	0	157	0	0
2	0	226	0	14	325	0	0
3	0	113	0	14	379	0	0
4	0	119	0	0	0	0	0
5	10	386	0	0	406	0	0
6	0	0	0	0	95	0	0

Table 6.3. Accumulative training and match load variables (representative of average data in bold and individual data from players 1-6) completed in the 7-day testing period and the day following the testing period. Running distance = distance covered between 14.4-19.8 km · h^{-1}, high-speed running distance = distance covered between 19.8-25.2 km · h^{-1} and sprinting distance = distance covered >25.2 km · h^{-1}. Each player's position is shown in brackets. CF=Centre Forward, WD=Wide Defender, WM=Wide Midfielder, CDM=Central Defending Midfielder, CAM= Central Attacking Midfielder and CD=Central Defender.

	Matches	Training	Total
Duration (min)	**142 ± 45**	**178 ± 22**	**321 ± 33**
1 (CF)	166	163	328
2 (WD)	191	163	353
3 (WM)	117	202	319
4 (CDM)	94	211	305
5 (CAM)	191	162	353
6 (CD)	96	169	266
Total Distance (m)	**16677 ± 5914**	**9760 ± 1852**	**26438 ± 5408**
1 (CF)	16937	7981	24918
2 (WD)	20602	7362	27963
3 (WM)	15489	11047	26536
4 (CDM)	11511	12311	23823
5 (CAM)	25792	10012	35804
6 (CD)	9733	9849	19582
Running Distance (m)	**2920 ± 1403**	**485 ± 202**	**3405 ± 1501**
1 (CF)	2257	307	2564
2 (WD)	3361	263	3624
3 (WM)	3182	655	3837
4 (CDM)	2400	701	3101
5 (CAM)	5253	647	5900
6 (CD)	1067	338	1405
High-Speed Running Distance (m)	**1218 ± 682**	**104 ± 46**	**1322 ± 717**
1 (CF)	1151	100	1251
2 (WD)	1519	108	1628
3 (WM)	1383	122	1505
4 (CDM)	592	124	716
5 (CAM)	2276	153	2429
6 (CD)	386	17	403
Sprinting Distance (m)	**423 ± 269**	**7 ± 7**	**430 ± 274**
1 (CF)	489	1	490
2 (WD)	552	14	566
3 (WM)	493	14	507
4 (CDM)	119	0	119
5 (CAM)	793	10	803
6 (CD)	95	0	95

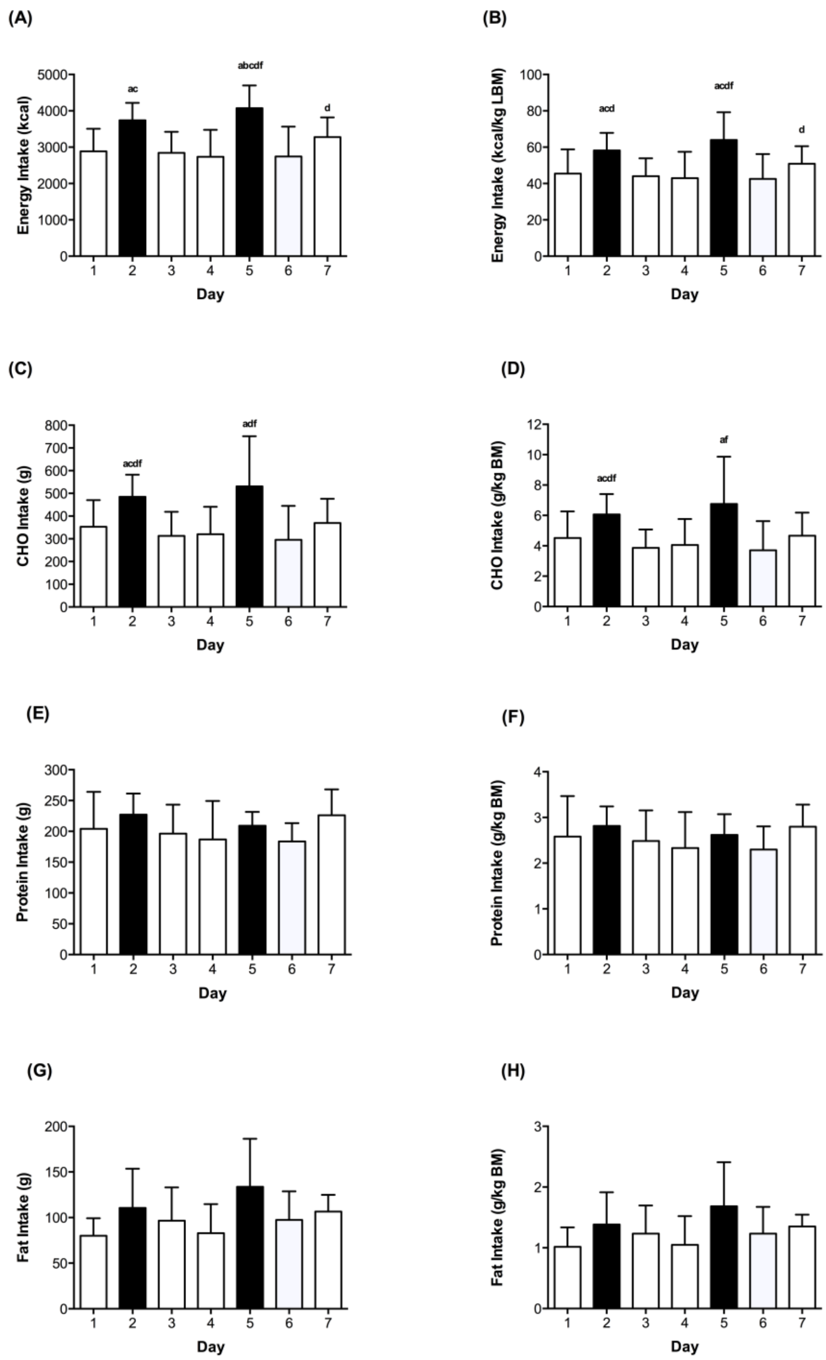


Figure 6.1. Daily energy and macronutrient intake expressed absolutely and relative to body mass over the 7-day testing period. Figure A=absolute energy expenditure, Figure B=energy expenditure relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat. White bars=training days and black bars=match days. a denotes difference from day 1, b denotes difference from day 2, c denotes difference from day 3, d denotes difference from day 4, e denotes difference from day 5, f denotes difference from day 6.

6.4.3. ENERGY AND MACRONUTRIENT INTAKE ON TRAINING VS. MATCH DAYS

EI and EI relative to LBM were also greater (both $P<0.05$) on match days (3789 ± 532 kcal; 61.1 ± 11.4 kcal·kg^{-1} LBM) compared with training days (2956 ± 374 kcal; 45.2 ± 9.3 kcal·kg^{-1} LBM, respectively). Additionally, CHO intake and CHO intake relative to body mass were also greater (both $P<0.05$) on match days (330 ± 98 g; 6.4 ± 2.2 g·kg^{-1}) compared with training days (508 ± 152 g; 4.2 ± 1.4 g·kg^{-1}).

6.4.4. ENERGY AND MACRONUTRIENT DISTRIBUTION ACROSS MEALS ON TRAINING DAYS

There were significant differences in the reported absolute and relative energy and macronutrient between meals consumed on training days ($P<0.01$ for all examined absolute and relative EI variables; see Figure 6.2.). Specifically, players consumed higher absolute and relative EI at dinner compared with breakfast, morning, afternoon and evening snacks ($P<0.01$ for all comparisons). Additionally, absolute and relative EI was also greater at lunch compared with the morning and evening snacks ($P<0.01$). Absolute and relative CHO intakes were higher at dinner compared with morning snack (both $P<0.01$), lunch (both $P<0.05$) and evening snack (both $P<0.01$), with relative CHO intake also being higher at dinner compared with breakfast ($P=0.04$).

Protein and relative protein intakes were greater at dinner compared with breakfast, morning snacks, afternoon snacks and evening snacks ($P<0.01$ for all comparisons). In addition, absolute and relative protein intakes were greater at lunch compared with breakfast, morning snacks and evening snacks ($P<0.01$ for all comparisons). Both absolute and relative protein intakes were also higher at breakfast compared with evening snack (both $P<0.02$) and higher at the afternoon snack compared with the evening snack (both $P<0.01$).

In relation to fat intake, both absolute and relative intakes were higher at dinner compared with the morning, afternoon snacks and evening snacks ($P<0.05$ for all comparisons). Additionally, fat intake was also higher at lunch compared with the morning snack ($P<0.01$ for both absolute and relative intakes).

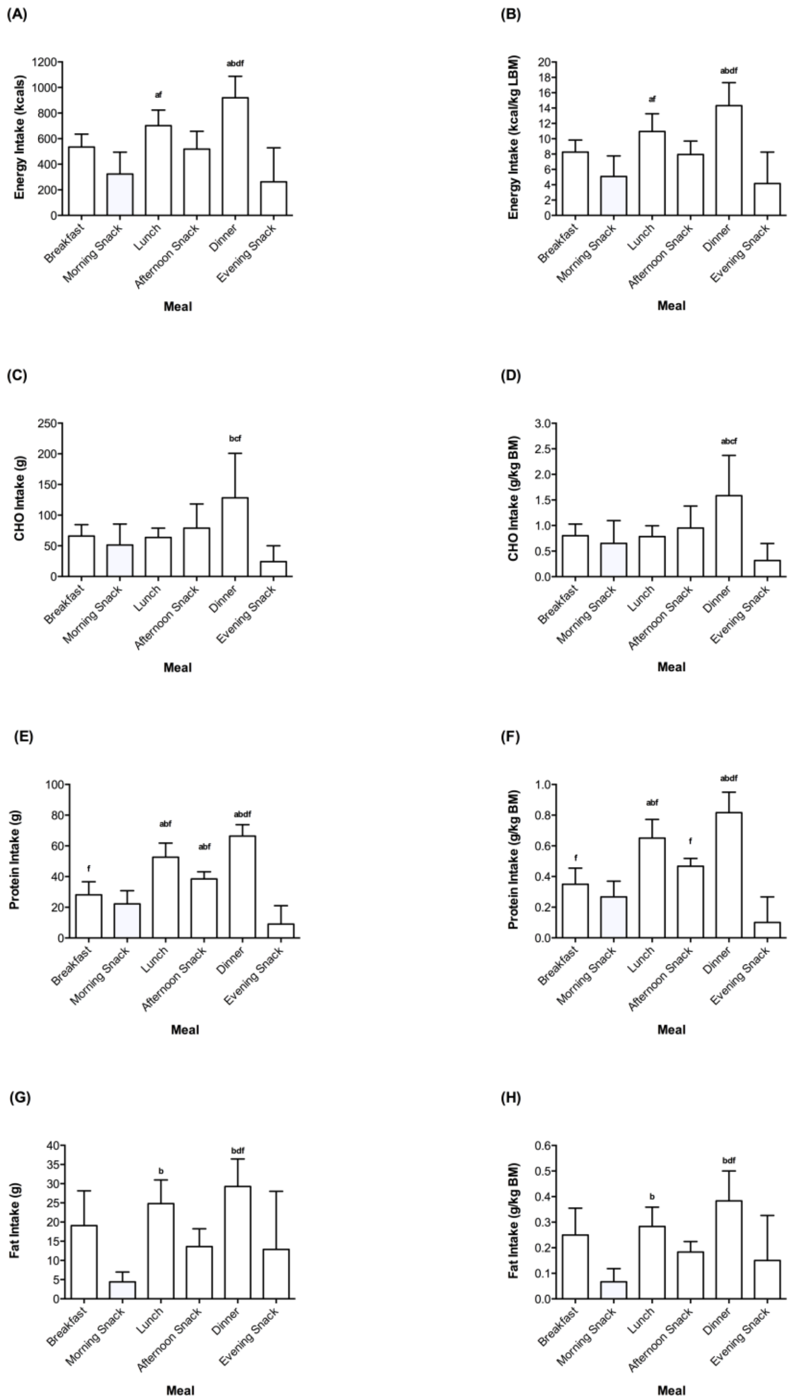


Figure 6.2. Energy and macronutrient intakes meal distribution on training days. Figure A=absolute energy expenditure, Figure B=energy expenditure relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat. a denotes difference from breakfast, b denotes difference from morning snack, c denotes difference from lunch, d denotes difference from afternoon snack, e denotes difference from dinner, f denotes difference from evening snack.

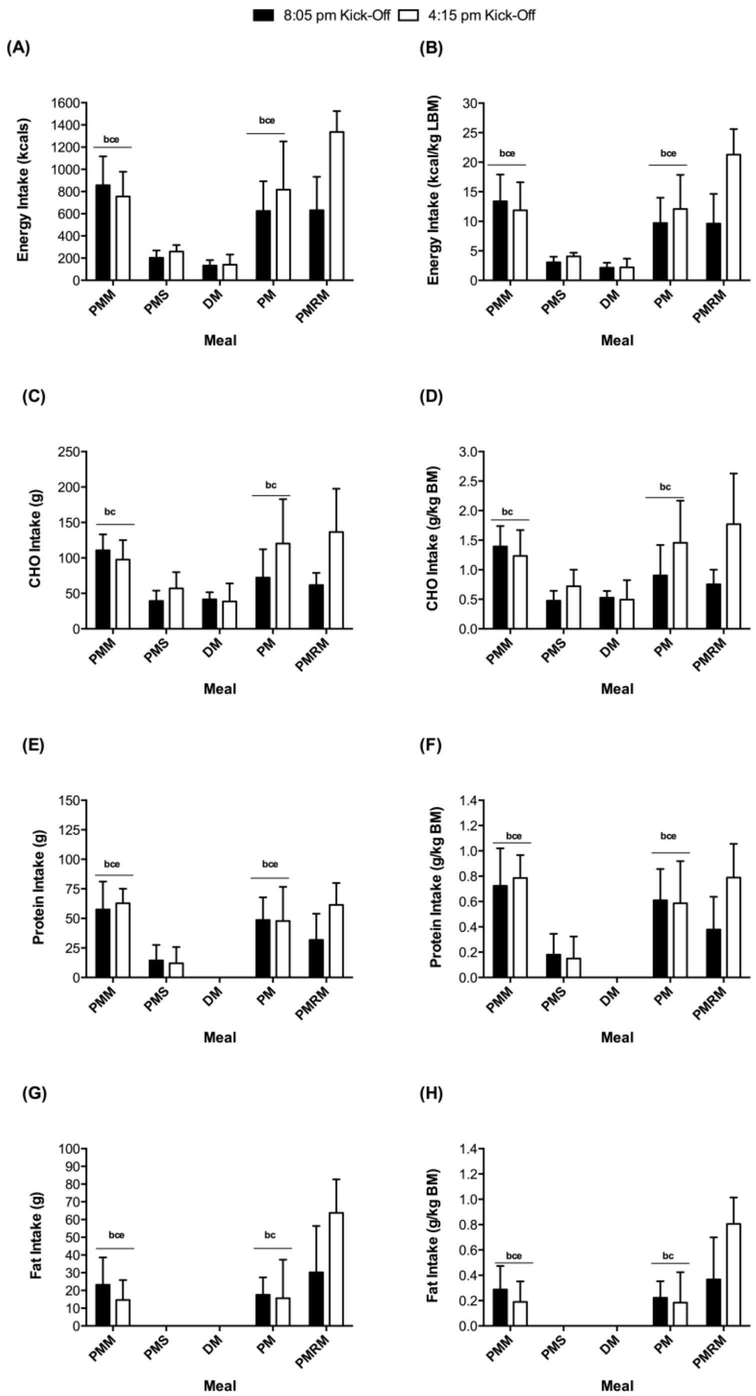


Figure 6.3. Energy and macronutrient intake meal distribution on the two match days during the study period. Black bars=match day 1 and white bars=match day 2. a denotes difference from PMM, b denotes difference from PMS, c denotes difference from DM, d denotes difference from PM, e denotes difference from PMRM. PMM=Pre Match Meal, PMS=Pre-Match Snack, DM=During-Match, PM=Post-Match, PMRM=Post-Match Recovery Meal.

6.4.5. ENERGY AND MACRONUTRIENT INTAKE ACROSS MEALS ON MATCH DAYS

There was no significant difference ($P>0.05$ for all meals; see Figure 6.3.) in absolute and relative energy and macronutrient intake between meals on the two different match days. However, significant differences were observed between meals consumed on match days for all energy and macronutrient variables (all $P<0.05$). The absolute and relative energy and protein intake were higher in the PMM and PM compared with the PMS, DM and PMRM (all $P<0.05$). Additionally, the absolute and relative CHO intake were also higher in the PMM and PM compared with the PMS and DM (all $P<0.05$). Fat intake in the PMM and the PM, when expressed in both absolute and relative terms, were higher than the PMS and DM (all $P<0.05$), where the PMM was also lower than the PMRM (both $P<0.05$).

6.4.6. CARBOHYDRATE INTAKE DURING TRAINING AND GAMES

The mean quantity of CHO consumed during the two competitive matches (32.3 ± 21.9 $g.h^{-1}$; Player 1-6 data: 25.1, 24.8, 70.9, 29.9, 38.3 and 4.9 $g.h^{-1}$, respectively) was significantly higher ($P<0.05$) than that consumed during training sessions (3.1 ± 4.4 $g.h^{-1}$; Player 1-6 data: 0, 0.3, 11, 0, 5.7 and 1.6 $g.h^{-1}$, respectively). During training, 80 and 20% of the CHO consumed was provided from gels and fluid, respectively. During match play, 63 and 37% of the CHO consumed was provided from gels and fluids, respectively.

6.4.7. ENERGY EXPENDITURE VS. ENERGY INTAKE

There were no significant differences ($P=0.16$; see Table 6.3.) between average daily EE (3566 ± 585 kcal) and EI (3186 ± 367 kcal), although one player did exhibit markedly lower self-reported EI compared with EE (see player 6). Accordingly, players' body mass did not significantly change ($P=0.84$) from before (80.4 ± 7.9 kg) to after the 7 day study period (80.3 ± 7.9 kg).

Table 6.3. Individual differences of average daily energy intake vs. average daily energy expenditure and body mass changes from Day 0 to Day 8. Each player's position is shown in brackets. CF=Centre Forward, WD=Wide Defender, WM=Wide Midfielder, CDM=Central Defending Midfielder, CAM= Central Attacking Midfielder and CD=Central Defender.

Player	Energy Intake (kcals)	Energy Expenditure (kcals)	Body Mass Day 0 (kg)	Body Mass Day 8 (kg)
1 (CF)	2817	3047	90.1	89.2
2 (WD)	2905	3050	73.2	73.7
3 (WM)	3563	3047	71.0	71.1
4 (CDM)	3166	3050	80.1	79.1
5 (CAM)	3701	4140	78.9	78.1
6 (CB)	2961	4400	89.0	88.9
Mean ± SD	**3186 ± 367**	**3566 ± 585**	**80.4 ± 7.9**	**80.0 ± 7.6**

6.5. DISCUSSION

The aim of the present study was to simultaneously quantify EI, EE, training and match load across a 7-day in-season period. In order to study a weekly playing schedule representative of elite professional players, elite players competing in the English Premier League during a weekly micro-cycle consisting of two match days and five training days were studied. To our knowledge, this was also the first to report direct assessments of EE (using the DLW method) in an elite soccer team competing in the English Premier League and European competitions over a 7-day period. In relation to the specific players studied herein, our data suggest that elite players: 1) appear capable of matching energy requirements to EI, 2) practice elements of CHO periodisation such that absolute daily CHO intake and exogenous CHO feeding is greater on match days compared with training days, 3) tend to under-consume CHO on match days in relation to the pre-match meal and post-match recovery meal, especially in recovery from an evening kick-off time and 4) adopt a skewed approach to feeding such that absolute EI, CHO and protein intake are consumed in a hierarchical manner of dinner>lunch>breakfast>snacks.

Key parameters of the physical loading reported here is similar to that previously observed by our group during a two game per week micro-cycle (Anderson et al., 2015), albeit where five days was present between games as opposed to the two-day period studied here. Indeed, similar accumulative weekly high-speed running (1322 v 1466 m, respectively) and sprint (430 v 519 m, respectively) distance were observed. This result was expected given that such high-intensity loading patterns are largely reflective of game time as opposed to training time (Anderson et al., 2016). Interestingly, the weekly accumulative total distance reported here was less than that observed previously (26.4 v 32.5 km), a finding likely attributable to the greater frequency of training sessions completed by each player during the five-day interim period (Anderson et al., 2015). Such data reiterate how subtle alterations to the match and training schedule affects weekly loading patterns.

The mean daily EI and EE data reported here suggest that elite players are capable of matching overall weekly energy requirements. It is noteworthy, however, that despite no player experiencing body mass loss or gain during the study period, two players appeared to be under-reporting EI as evidenced by a mismatch between EI versus EE data. The mean daily EE (3566 ± 585 kcals) and EI (3186 ± 367 kcals) observed here agrees well that previously observed in professional Japanese players (3532 ± 432 and 3113 ± 581 kcal, respectively) where both DLW and 7-day food diaries were also used as measurement tools (Ebine et al., 2002). Although these authors did not provide any data related to physical loading, the similarity between studies is likely related to these researchers also studying a two-game per week playing schedule where consecutive games were also separated by two days. Interestingly, our EE data are much lower than that reported by our group for professional rugby players (5378 ± 645 kcal), thereby providing further evidence that nutritional guidelines for team sports should be specific to the sport and athlete in question (Morehen et al., 2016)

A limitation of the DLW technique is the inability to provide day-to-day EE assessments hence data are expressed as mean EE for the 7-day data collection period. Nonetheless, the players studied here appear to adopt elements of CHO periodisation in accordance with the upcoming physical load and likely differences in day-to-day EE. For example, both absolute and relative daily energy and CHO intake was greater on match days (3789 ± 577 kcal and 6.4 ±

2.2 g.kg^{-1}, respectively) compared with training days (2948 ± 686 kcal and 4.2 ± 1.4 g.kg^{-1}, respectively). Such differences in daily EI also agrees with recent observation from adult professional players of the Dutch league (Bettonviel et al., 2016) where subtle differences were observed between match days, training days and rest days (3343 ± 909, 3216 ± 834 and 2662 ± 680 kcal, respectively). It is also noteworthy that there was an observed greater EI on day 7 (prior to another match undertaken on day 8) versus day 4 (prior to match day 2). Such differences may reflect additional EI that is consumed prior to and during travelling (i.e. snacks provided on the bus) to the away game on day 8.

In the context of a two game week, however, it is likely that players did not consume adequate CHO to optimise muscle glycogen storage in the day prior to and in recovery from the games (Krustrup et al., 2006; Bassau et al., 2002). This point is especially relevant considering the inability to fully replenish muscle glycogen content in type II fibres 48 h after match play, even when CHO intake is > 8 g.kg^{-1} body mass per day (Gunnarsson et al., 2013). In this present study, it was also observed that CHO intakes would be considered sub-optimal in relation to maximizing rates of post-match muscle glycogen re-synthesis (Jentjens & Jeukendrup, 2003). Indeed, in contrast to the well-accepted guidelines of 1.2 g.kg^{-1} body mass for several hours post-exercise, it was observed that intakes of <1 g.kg^{-1} were reported in the immediate period after match day 1 (i.e. the night-time kick off). Such post-game intakes coupled with the relatively low absolute daily intake (i.e. 4 g.kg^{-1}) on the subsequent day would inevitably ensue that absolute muscle glycogen re-synthesis was likely compromised, an effect that may be especially prevalent in type II fibres (Gunnarsson et al., 2013). It is noteworthy, however, that the high absolute protein intakes consumed in the post-match period (i.e. >50 g) would likely potentiate rates of muscle glycogen re-synthesis when consumed in the presence of sub-optimal CHO availability (Van Loon et al., 2000).

In relation to match day itself, it could also be suggested that players did not meet current CHO guidelines for which to optimise aspects of physical (Burke et al., 2011), technical (Ali & Williams, 2009; Russell & Kingsley, 2014) and cognitive (Welsh et al., 2002) performance. Interestingly, CHO intake during match play was highest in players 3 and 5 who also tended to be the players (midfielders) with the greatest physical load on match days. Positional differences may therefore contribute to habitual fuelling strategies. When taken together, data suggest that players may benefit from consuming greater amounts of CHO in the day prior to and in recovery from match play (so as to optimise muscle glycogen storage) as well as consume greater amounts of CHO during exercise to maximise the aforementioned components of soccer performance. In this regard, both the pre-match meal (< 1.5 $g.kg^{-1}$ body mass) and CHO feeding during match play (~30 $g.h^{-1}$; four players consumed <30 $g.h^{-1}$) could be considered sub-optimal in relation to those studies (Wee et al., 2005; Foskett et al., 2008) demonstrating higher CHO intakes (e.g. 2-3 $g.kg^{-1}$ body mass and 60 $g.h^{-1}$, respectively) induce physiological benefits that are facilitative of improved high-intensity intermittent performance e.g. high pre-exercise glycogen stores, maintenance of plasma glucose/CHO oxidation during exercise and muscle glycogen sparing.

Although there is evidence of CHO periodisation during the week, players reported consistent daily protein and fat intakes. Interestingly, absolute and relative daily protein intakes were higher (205 ± 30 g) than that reported two decades ago in British professional players (108 ± 26 g), whereas both CHO and fat intake were relatively similar (Maughan, 1997). Our observed daily protein intakes also agree well with those reported recently (150-200 g) in adult professional players from the Dutch league (Bettonviel et al., 2016). Such differences between eras are potentially driven by the increased scientific research and resulting athlete (and coach) awareness of the role of protein in facilitating training adaptations and recovery from both aerobic and strength training (Moore et al., 2014; McNaughton et al., 2016).

Recent data also suggest that the timing and even distribution of daily protein doses may have a more influential role in modulating muscle protein synthesis rates in responses to both feeding alone (Mamerow et al., 2014) and post-exercise feeding (Areta et al., 2013). In this regard, a skewed pattern of daily protein intake in that absolute protein was consumed in a hierarchical order where dinner>lunch>breakfast>snacks was observed. This finding also agrees with our previous observations on the protein feeding patterns of elite youth soccer players (Naughton et al., 2016) as well as adult players from the Dutch league (Bettonviel et al., 2016) and a mixed sex cohort of Dutch athletes (Gillen et al., 2016). Based on recent data suggesting that trained athletes (especially those with higher lean mass) may require protein doses of approximately 40 g (McNaughton et al., 2016) as well as the importance of protein feeding prior to sleep (Res et al., 2012), our data suggest that breakfast and morning, afternoon and bedtime snacks are key times to improve for the present sample. It must be acknowledged, however, that protein requirements (both in absolute dosing and timing) should be tailored to the specific population in question in accordance with timing of training sessions, training load and moreover, individualised training goals.

Additionally, it was also observed that CHO ingestion was significantly during training sessions (3.1 ± 4.4 $g.min^{-1}$) compared with matches (32.3 ± 21.9 $g.min^{-1}$). Furthermore, the breakfast and lunch (<1 $g.kg^{-1}$) consumed on training days (that effectively serve as the pre-training meal) also tended to be lower in CHO content than that consumed in the PMM (1-1.5 $g.kg^{-1}$). It is, of course, difficult to ascertain whether such alterations to CHO fuelling patterns were a deliberate choice of the player and/or a coach (sport scientist) led practice or moreover, an unconscious choice. Nonetheless, such choices appear to be in accordance with the "fuel for the work required" principle (Impey et al., 2016) in that carefully chosen periods of reduced CHO availability may lead to work-efficient skeletal muscle cell signaling processes that regulate components of training adaptation (Bartlett et al., 2015; Hawley & Morton, 2015).

Despite the novelty and practical application of the current study, our data are not without limitations, largely a reflection of the practical demands of data collection in an elite football setting. Firstly, the simultaneous use of both GPS and Prozone® to quantify training and competitive match demands, respectively, has implications for the comparability of data between systems (Harley et al., 2011; Buchheit et al., 2014). However, it is not yet common policy to use GPS during competitive games due to managers' preferences, players' comfort issues and poor signal strength due to roofing in many of the stadiums in the English

Premier League. Secondly, this study is reflective of only six players from one team only (albeit reflective of a top English Premier League team) and hence may not be representative of the customary training and nutritional habits of other teams. Nonetheless, players were deliberately recruited from different playing positions in an attempt to provide a more representative sample of professional soccer players. Thirdly, as with all dietary analysis studies, our data may be limited by both under-reporting and inter-researcher variability in ability to assess dietary intakes. Indeed, whilst there were no significant group mean changes in body mass over the data collection period, two of our subjects did appear to under report whereas four of the subjects reported EI data that was comparable (within 200 kcal) to EE data. Finally, both of the games studied here represented home games and hence the nutritional choices are likely to be influenced by the philosophy and service provision of the club coaching and catering staff.

6.6. CONCLUSION

In summary, this study simultaneously quantified for the first time the daily physical loading, EI and EE during a weekly micro-cycle of elite level soccer players from the English Premier League. Although players appear capable of matching daily energy requirements to EI, elements of CHO periodisation in that players consumed higher amounts of CHO on match days versus training days were also observed. Moreover, CHO intakes were below that which is currently recommended for when players are completing 2 competitive games in close proximity to one another. Additionally, whilst daily protein intake was consistent throughout the week, absolute daily protein intake was greater than previously reported in the literature and was consumed in a hierarchical manner such that dinner > lunch > breakfast > snacks. These data suggest that players may benefit from consuming greater amounts of CHO in the day prior to and in recovery from match play so as to optimise muscle glycogen storage. Furthermore, attention should also be given to even distribution of daily protein intake so as to potentially promote components of training adaptation.

CHAPTER 7

CASE STUDY: ENERGY INTAKE AND ENERGY EXPENDITURE IN A PREMIER LEAGUE GOALKEEPER DURING A TYPICAL IN-SEASON MICRO-CYCLE

Whilst studies 1-3 focused on outfield players, it is currently difficult to prescribe nutritional guidelines for the soccer goalkeeper due to a lack of understanding of training load and energy expenditure. The aim of this chapter was to therefore quantify physical load, energy intake and energy expenditure of an English Premier League goalkeeper.

7.1. ABSRACT

Professional goalkeepers (GK) in elite soccer have different match and likely different training demands than their outfield teammates. Due to a lack of scientific understanding of the energy demands and actual demands of GK training, it is difficult to provide GK specific nutritional recommendations. Therefore, in an attempt to further understand the nutritional requirements of a GK, the aim of this study was to provide a case-study account of a GKs typical daily training loads, average daily EE and daily EI as assessed using GPS and ProZone®, food diaries (supported by the RFPM and 24 h recalls) and the DLW method. Although mean daily EE (2894 kcals) and EI (3160 kcals) were similar, EI was greater on MD (3475 kcals) compared with TD (3034 kcals). Differences in EI were reflective of greater daily CHO intake on MD (3.3 $g.kg^{-1}$) compared with TD (2.3 $g.kg^{-1}$). In contrast, daily protein (2.4 $g.kg^{-1}$) and fat intake (1.9 $g.kg^{-1}$) did not display any evidence of daily periodisation. A skewed daily distribution of energy, CHO, protein and fat intake on TD such that parameters were typically greater in lunch and dinner compared with breakfast and snacks was also observed. Additionally, the GK failed to meet current recommendations for meals on match day that could facilitate an improvement in performance and post-match recovery. Although the GK is currently meeting his energy demands, it is recommend he adopts a more balanced approach to protein feeding throughout the day and increases CHO consumption around matches in order to potentially facilitate performance and recovery improvements.

7.2. INTRODUCTION

The GK in soccer is required to demonstrate a high level of proficiency in various actions related to both defensive and offensive aspects of the game (Welsh, 1999). In competitive matches, a GK covers significantly less total distance (5611 ± 613 m vs. 10841 ± 950 m) and distance in high-intensity speed zones (>19.8 km · h^{-1}) than their outfield teammates (56 ± 34 m vs. 980 ± 294 m) (Di Salvo et al., 2008; Bradley et al., 2010). Rather, the demands of a GK are assessed mainly on his ability to perform high-intensity movements and explosive actions which are separated by longer walking and jogging periods that allow for recovery (Ziv & Lidor, 2011). They are required to have high levels of concentration throughout the game in order to be prepared to perform unexpected actions. In training sessions, GKs often train separately from the rest of the squad and thus, are likely to have different training demands to outfield players.

Typically, GKs are taller, heavier and have higher levels of body fat than players in other positions in the team (Milsom et al., 2015; Sutton et al., 2009). This is undoubtedly a cause for concern as excess fat mass acts as a dead mass in activities in which the body is lifted repeated against gravity (Reilly, 1996). In this regard, practitioners strive to implement different nutritional strategies that support the physical and mental demands of a GKs training and match program. It is also of importance to educate these players on food 'choices', as many of the foods that are traditionally prescribed by club support staff are high in energy and CHO due to the demands of outfield positions (Anderson et al., 2017, Chapter 6). Nevertheless, no data currently exists examining the EE and EI of an elite professional GK, nor is there any information regarding training load in the typical weekly micro-cycle. It is therefore difficult to currently provide position specific nutritional guidelines for GKs.

With this in mind, the aim of this case study was to quantify training load, match load, EE and EI of an International-standard English Premier League GK over a weekly micro-cycle. This will enable sports nutritionists to have a more detailed understanding of nutritional requirements in order to tailor programs specific to the needs of GK.

7.3. METHODS

7.3.1. OVERVIEW OF THE PLAYER

The player is a 27-year old male professional GK (body mass 86.1 kg, height 191 cm, body fat 11.9 %, fat mass 9.8 kg, lean mass 69.5 kg) who is internationally capped and currently competing in the English Premier League. He made his professional debut when he was 18 and has been a regular starter at his club for 2.5 seasons prior to this study commencing. Due to competing in regular weekly league matches and success in both domestic and European cup competitions the player is often competing in games every 3-4 days. Throughout his 2.5 years at the club and at the time of study he was clear of injury and a regular starter for his club and country.

7.3.2. STUDY DESIGN

The data collection was conducted during the English Premier League 2015-2016 season. This player underwent a body composition assessment in line with section 3.3. The training and match load were collected and analysed as described in section 3.4. However, although the same methods were used for data collection, a specific GK GPS device was used to assess training load (Version G5, Catapult Innovations, Melbourne, Australia). Throughout the study period, the player took part in 6 training sessions (which were monitored using GPS) and 2 competitive games to (which were monitored via Prozone®). Energy expenditure measurements were collected, stored and analysed using methods described in section 3.5. Energy and macronutrient intakes were assessed and analysed using methods described in section 3.6. The study was conducted according to the requirements of the Declaration of Helsinki and was approved by the university ethics committee of Liverpool John Moores University.

7.3.3. MEASUREMENT OF ENERGY EXPENDITURE USING DOUBLY LABELED WATER

Energy expenditure measurements were collected, stored and analysed using methods described in section 3.5.

7.3.4. ASSESSMENT OF TOTAL DIETARY INTAKE

Energy and macronutrient intakes were assessed and analysed using methods described in section 3.6.

7.4. RESULTS

7.4.1. QUANTIFICATION OF DAILY AND ACCUMULATIVE WEEKLY LOAD

An overview of the individual daily training and match load and the accumulative weekly load is presented in Table 7.1.

Table 7.1. An overview of the absolute and accumulative training, match and total physical demands of the player during data collection

	Day 1	Day 2 am	Day 2 pm	**Day 2 Total**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**	**Training**	**Match**	**Total**
Duration (mins)	68	36	94	130	45	61	96	32	52	294	190	484
Total Distance (m)	2422	1393	4879	6272	1800	2367	4268	1379	2392	11753	9147	20900
Average Speed (m/min)	35.5	38.8	51.8	48.2*	40.0	38.8	44.3	43.7	46.0	-	-	-
Standing (0-0.6 km . hr^{-1})	868	400	85	485	374	746	109	431	780	3599	194	3793
Walking (0.7-7.1 km . hr^{-1})	825	482	3526	4008	686	876	3137	298	989	4156	6663	10819
Jogging (7.2-14.4 km . hr^{-1})	716	511	1130	1641	712	702	856	607	623	3871	1986	5857
Running (14.4-19.7 km . hr^{-1})	13	0	126	126	28	42	149	43	0	126	275	401
HSR (19.8-25.2 km . hr^{-1})	0	0	9	9	0	0	17	0	0	0	26	26
Sprinting (>25.2 km . hr^{-1})	0	0	4	4	0	0	0	0	0	0	4	4

* = the sum of both sessions total distance / the sum of both sessions duration, Day 2 pm and Day 5 were both competitive fixtures.
HSR = High speed running

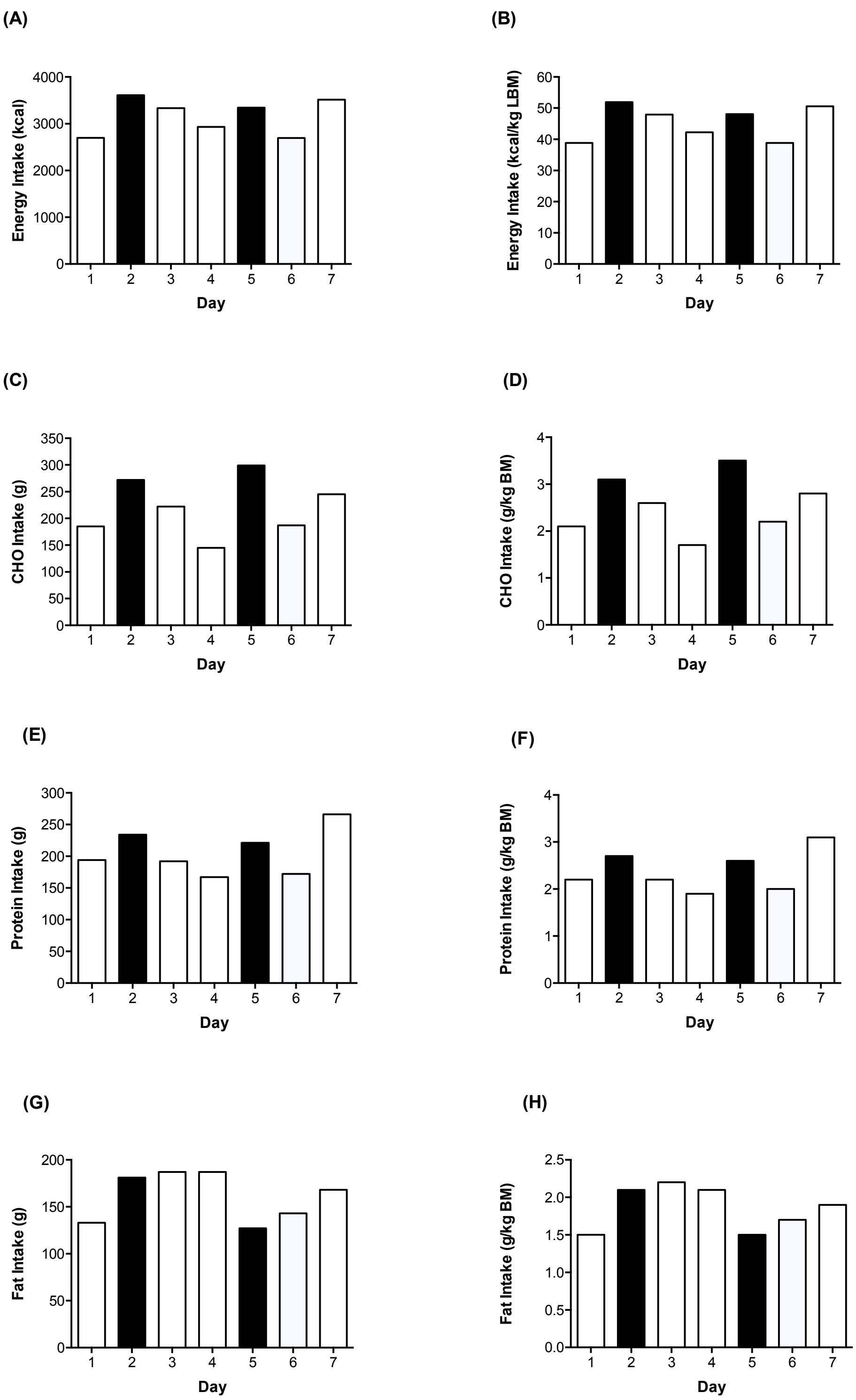


Figure 7.1. Daily energy and macronutrient intake expressed absolutely and relative to body mass over the 7-day testing period. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat. White bars=training days and black bars=match days.

7.4.2. QUANTIFICATION OF DAILY ENERGY AND MACRONUTRIENT INTAKE

A comparison of daily energy and macronutrient intake is presented in Figure 7.1. On average, the player's EI was 3160 kcals (2695 – 3607 kcals) across the week. Additionally, his average daily absolute and relative CHO intake was 222 g (145 – 299 g) and 2.6 $g \cdot kg^{-1}$ (1.7 – 3.5 $g \cdot kg^{-1}$). Moreover, the player's average daily absolute and relative protein intake was 207 g (167 – 266 g) and 2.4 $g \cdot kg^{-1}$ (1.9 – 3.1 $g \cdot kg^{-1}$). Lastly the player's average daily absolute and relative fat intake remained similar throughout the week 160 g (133 – 187 g) and 1.9 $g \cdot kg^{-1}$ (1.5 – 2.2 $g \cdot kg^{-1}$).

Energy intake and EI relative to LBM were greater on match days (3475 kcals; 50.0 $kcal \cdot kg^{-1}$ LBM) compared with training days (3034 kcals; 43.7 $kcal \cdot kg^{-1}$ LBM). This coincided with an increase in absolute and relative CHO intakes on match days (286 g; 3.3 $g \cdot kg^{-1}$) compared with training days (197 g; 2.3 $g \cdot kg^{-1}$). It could be suggested that the player's absolute and relative protein intakes remain consistent on match days (228 g; 2.6 $g \cdot kg^{-1}$) compared with training days (198 g; 2.3 $g \cdot kg^{-1}$). However, on day 7 the player consumes a large protein intake compared to the weekly average (266 g; 3.1 $g \cdot kg^{-1}$). The players' absolute and relative fat intake is consistent throughout the week on both match days (154 g; 1.8 $g \cdot kg^{-1}$) and training days (164 g; 1.9 $g \cdot kg^{-1}$).

7.4.3. ENERGY AND MACRONUTRIENT DISTRIBUTION ACROSS MEALS ON TRAINING DAYS

Absolute and relative energy and macronutrient intakes across meals on training days are displayed in Figure 7.2. Both absolute and relative EI are greater at Lunch, Dinner and Breakfast compared with Afternoon Snack, Evening Snack and Morning Snack. Additionally, all macronutrients (both absolute and relative) follow a similar pattern with the macronutrients being unevenly distributed in the hierarchical order Lunch >> Dinner >> Breakfast >> Afternoon Snack >> Evening Snack >> Morning Snack.

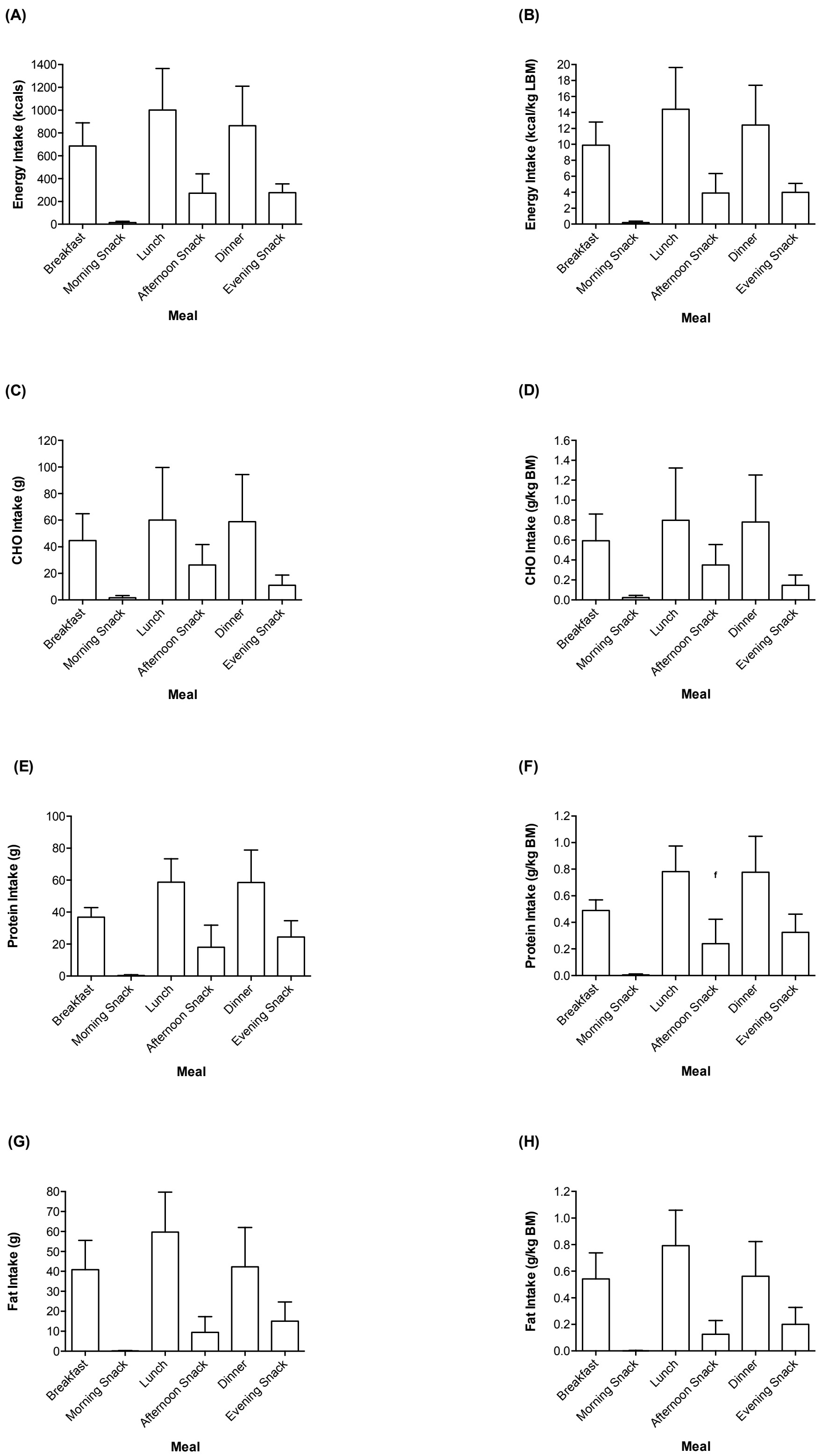


Figure 7.2. Energy and macronutrient intakes meal distribution on training days. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat.

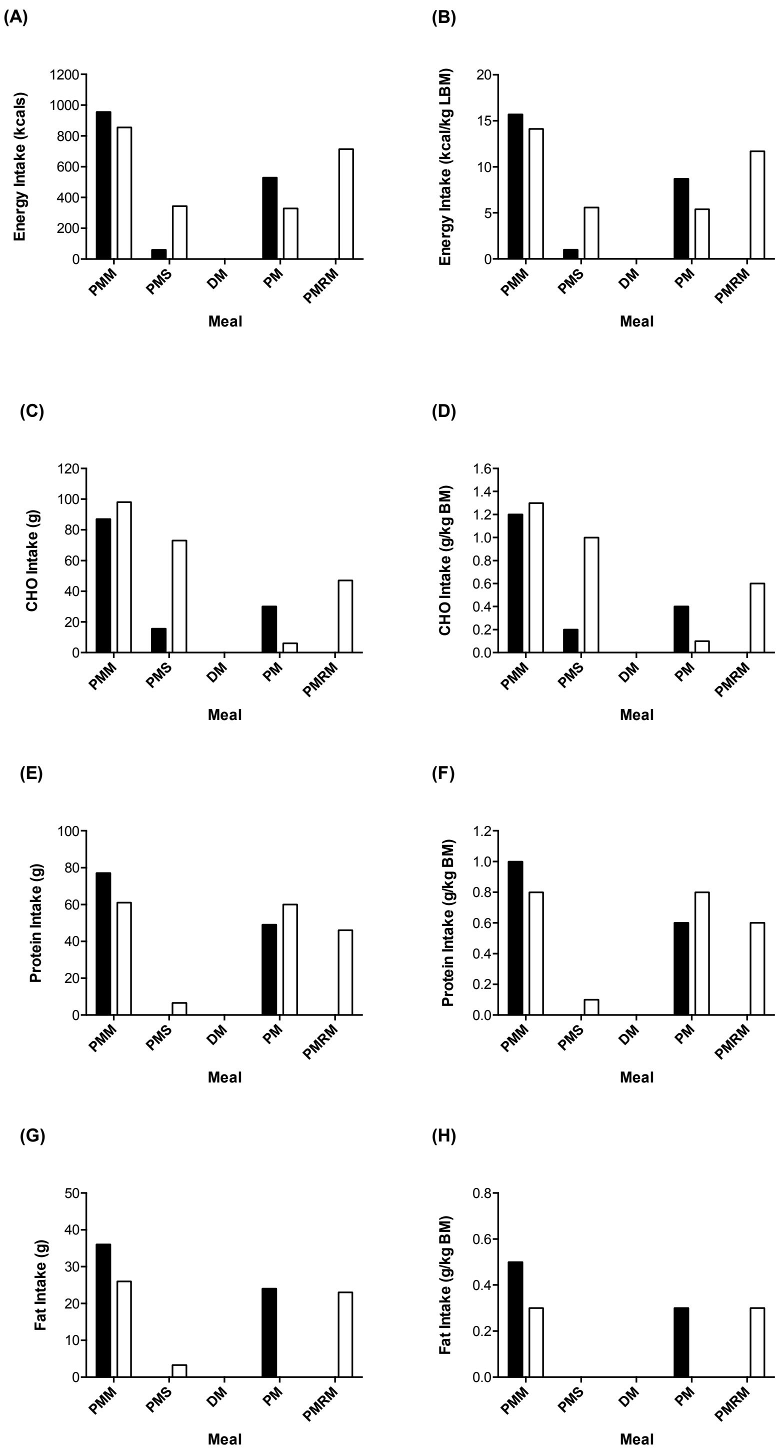


Figure 7.3. Energy and macronutrient intake meal distribution on the two match days during the study period. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat. Black bars=match day 1 and white bars=match day 2. PMM=Pre Match Meal, PMS=Pre-Match Snack, DM=During-Match, PM=Post-Match, PMRM=Post-Match Recovery Meal.

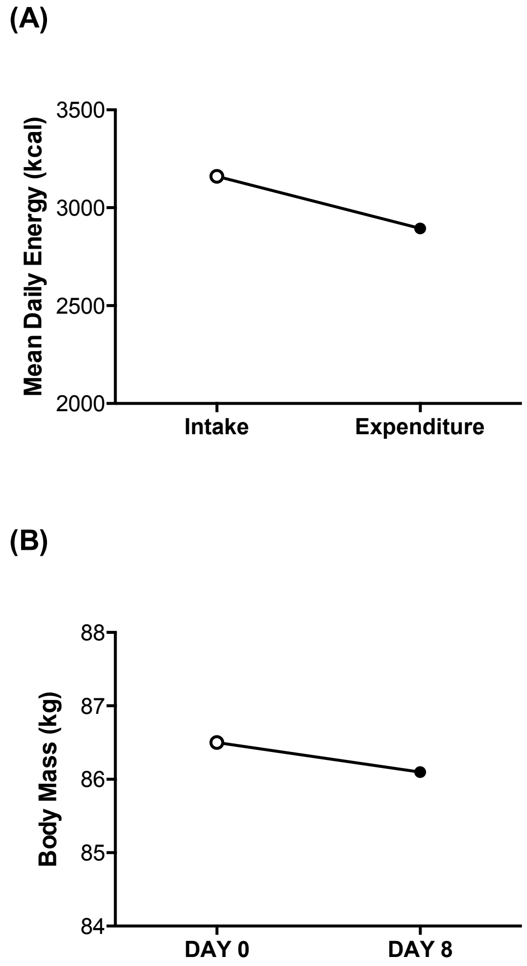


Figure 7.4. Differences in average daily energy intake vs. average daily energy expenditure and body mass changes from day 0 to day 8. Figure A=energy intake vs. energy expenditure and Figure B=body mass changes.

7.4.4. ENERGY AND MACRONUTRIENT DISTRIBUTION ACROSS MEALS ON MATCH DAYS

Absolute and relative energy and macronutrient intakes across meals on match days are displayed in Figure 7.3. Higher amounts of energy and macronutrients were consumed in the PMS on match day 2 compared with match day 1. However, greater amounts of energy and macronutrients were consumed PM in match 1 compared with match 2. Moreover, the energy and macronutrients were greater for the PMRM in match day 2 compared with match day 1. The player presents a skewed approach to feeding across meals around matches.

7.4.5. CARBOHYDRATES DURING TRAINING AND GAMES

Throughout the duration of this study the player only consumed bottled water during training and matches.

7.4.6. ENERGY EXPENDITURE VS. ENERGY INTAKE

The average daily EI and EE along with any subsequent body mass changes over the examination period are shown in Figure 7.4. On average, the player was consuming 3160 kcals and expending 2894 kcals, giving an average daily surplus of 266 kcals. Over the weekly micro-cycle the player subsequently lost -0.4 kg in body mass.

7.5. DISCUSION

The aim of the present study was to simultaneously quantify EI, EE, training and match load across a 7-day in-season period for an English Premier League GK. In order to study a weekly playing schedule representative of an elite GK, a player who was competing in a micro-cycle consisting of two match days and 5 training days were studied. This is the first to report direct measurements of EE (using the DLW method) in an elite English Premier League GK. In relation to the specific GK studied, our data suggest that he: 1) slightly exceeds energy demands when assessed using the current dietary method, 2) practices elements of CHO periodisation such that CHO intake is greater on match days compared with training days, 3) tends to under-consume CHO on match days in relation to the pre-match meal and post-match recovery and 4) adopts a skewed approach to feeding such that absolute EI, CHO and protein intake are consumed in a hierarchical manner of lunch>dinner>breakfast>snacks.

For the first time, key parameters of physical loading are reported here for GKs during training and are remarkably similar to loads produced from the same team's outfield players (TD=2422 m vs. 2865 m; HID=0 m vs. 32 m) during the same competitive week (Anderson et al., 2017; Chapter 6). However, the training loads for outfield players when two matches are played over a weekly micro-cycle are typically focused around physical recovery and preparation for the next competitive match (Anderson et al., 2015; Chapter 4). As such, further research is required to examine GKs typical weekly training loads over a one-game per week schedule and compare against outfield players. In addition to training, match load is less than reported previously (TD= 4879m vs. 5611m; HID=13 vs. 56 m) (Di Salvo et al., 2008; Bradley et al., 2010) and to other outfield positions (Anderson et al., 2015; Anderson et al., 2017; Chapters 4 and 6). Therefore, the accumulative weekly load is considerably less than reported in outfield players. Indeed, it is extremely useful to understand the movement demands of GKs and these data give a valuable insight into the training and accumulatively weekly demands, allowing a more detailed understanding of the energy requirements during training and matches. However, the demands of GKs are assessed mainly on their ability to perform high-intensity movements and explosive actions (such as jumps and dives) using quick reaction speed, which often increases the load and increases the players perceived exertion (Ziv & Lidor, 2011). Until validation work is published on recent developments in GPS units regarding GK specific actions, the research is limited to the movement demands only.

The mean daily EI and EE data reported here suggest that an elite GK is generally capable of matching overall weekly energy requirement. It is notable, however, that the player experienced a -0.4 kg loss in body mass over the study period despite over consuming on average 266 kcals per day (1862 kcals over the week). The mean daily EE (2894 kcals) was considerably less than that observed in outfield players using this method previously (3566 kcals), although EI was similar here (3160 kcals) compared to outfield players (3186 kcals) (Anderson et al., 2017; Chapter 6).

A limitation of the DLW technique is the inability to provide day-to-day EE assessments hence data are expressed as mean EE for the 7-day data collection period. Nevertheless, the GK studied here appears to adopt elements of CHO periodisation in accordance with match play and training demands. For example, both absolute and relative daily energy and CHO intake was greater on match days (3475 kcal and 3.3 $g.kg^{-1}$, respectively) compared with training days (3034 kcal and 2.3 $g.kg^{-1}$, respectively). Such differences in daily EI also agree with recent observation from adult professional outfield players of the Dutch league (Bettonviel et al., 2016) where subtle differences were observed between match days, training days and rest days (3343 ± 909, 3216 ± 834 and 2662 ± 680 kcal, respectively). It is also noteworthy that a greater energy, CHO and protein intake on day 7 (prior to another match undertaken on day 8) versus days 1 and 4 (prior to match day 1 and 2) were observed. Such differences may reflect additional high CHO and high protein foods that are made available and consumed prior to and during travelling (i.e. snacks provided on the bus) to the away game on day 8. This trend is similar to that observed in the outfield positions during this competitive week (Anderson et al., 2017; Chapter 6).

Although it is not currently known, it is unlikely that GK need to consume CHO in quantities similar to outfield players in order to optimise muscle glycogen storage in the day prior and in recovery from games (Krustrup et al., 2006; Bassau et al., 2002). However, in the present study, CHO intakes that would be considered sub-optimal in relation to maximizing any worthy muscle glycogen re-synthesis were observed (Jentjens & Jeukendrup, 2003). Indeed, whilst it is likely that the GKs would still require 1.2 $g.kg^{-1}$ body mass in the immediate hour after match play, reported intakes of < 0.4 $g.kg^{-1}$ in the immediate period after match day 1 (i.e. the night-time kick off) were observed. Such post-game intakes coupled with the relatively low absolute daily CHO intakes (i.e. 2.3 $g.kg^{-1}$) on the subsequent day would likely ensure that the player is competing with low muscle glycogen. It is noteworthy, however, that the high absolute protein intakes consumed in the post-match period (i.e. >50 g) would likely potentiate rates of muscle glycogen re-synthesis when consumed in the presence of sub-optimal CHO availability (Van Loon et al., 2000).

In relation to match day itself, it could also be suggested that the player did not meet current CHO guidelines for which to optimise aspects of physical (Burke et al., 2011), technical (Ali & Williams, 2009; Russell & Kingsley, 2014) and cognitive (Welsh et al., 2002) performance. Although Anderson et al. (2017; Chapter 6) observed there were positional differences in CHO fuelling strategies during games, with midfield players' intakes being highest and reflective of their physical load, the GK consumed only bottled water and caffeine to increase cognitive performance during match play (Foskett et al., 2009). It could be suggested that in order to maintain plasma glucose during matches, elite level GK should consume CHO based supplements.

In addition to the GK undergoing CHO periodisation throughout the weekly micro-cycle, he also tends to consume higher protein on match days (228 g) compared with training days (198 g). Moreover, fat intakes ranged from 127 to 187 g but displayed no evident of periodisation. Interestingly, these protein intakes were higher than British professional outfield players (108 ± 26 g), whereas average fat were similar (118 ± 24 g), respectively (Maughan, 1997). These protein intakes are similar to that observed in outfield players (205 ± 30 g) and also with those reported recently (150-200 g) in adult professional players from the Dutch League (Bettonviel et al., 2016). These differences have possibly derived from increased scientific research and a greater player awareness of the importance of protein in facilitating training adaptations and recovery from both aerobic and strength training (Moore et al., 2014; McNaughton et al., 2016).

Recent data suggests that not only the total daily intake of protein, but the timing and even distribution of protein doses may have more influential role in modulating muscle protein synthesis rates in responses to both feeding alone (Mamerow et al., 2014) and post-exercise feeding (Areta et al., 2013). In the present study it was observed that this GK undertakes a skewed pattern of daily protein intake in that absolute protein was consumed in a hierarchical order where lunch>dinner>breakfast>snacks. This finding also agrees with our previous observations on the protein feeding patterns of elite outfield players (Anderson et al., 2017; Chapter 6) and elite youth soccer players (Naughton et al., 2016) as well as adult players from the Dutch league (Bettonviel et al., 2016) and a mixed sex cohort of Dutch athletes (Gillen et al., 2016). Based on recent data suggesting that trained athletes (especially those with higher lean mass) may require protein doses of approximately 40 g (McNaughton et al., 2016) as well as the importance of protein feeding prior to sleep (Res et al., 2012), our data suggest that breakfast and morning, afternoon and bedtime snacks are key times to improve for the present sample. However, protein requirements (both in absolute dosing and timing) should be tailored to the specific population in question in accordance with timing of training sessions, training load and moreover, individualised training goals.

7.6. CONCLUSION

In summary, this study simultaneously quantified for the first time the daily physical loading, EI and EE during a weekly micro-cycle of an elite level soccer GK from the English Premier League. Although he appears capable of matching daily energy requirements to EI, he practices elements of CHO periodisation in that he consumes higher amounts of CHO on match days versus training days. Moreover, his CHO intakes before, during and after matches are below that what is currently recommended for soccer players, albeit outfield players. Additionally, whilst daily protein intake was high throughout the week and higher to that reported previously, it was consumed such that lunch > dinner > breakfast > snacks. These data suggest that this professional GK may benefit from consuming greater amounts of CHO around the proximity of matches as to optimise performance and recovery. Furthermore, attention should be given to the even distribution of daily protein intake so as to potentially promote components of training adaptations.

CHAPTER 8

CASE STUDY: ENERGY INTAKE AND ENERGY EXPENDITURE IN A PREMIER LEAGUE SOCER PLAYER DURING REHABILITATION FROM ACL INJURY

Having now quantified the physical loading, energy expenditure and energy intakes of fully fit players (both outfield players and the GK), the aim of this chapter was to examine the energy expenditure and current energy intakes of a soccer player from the English Premier League who was recovering from an anterior cruciate ligament reconstruction.

8.1. ABSTRACT

Major injury in professional soccer imposes lengthy periods of immobilization and rehabilitation which present major challenges in maintaining muscle mass and function. There is an obvious nutritional challenge to the practitioner to attempt to prevent muscle atrophy due to lack of information on players daily EE and whether that is being matched by daily EI. A 10-month case study with a specific focus on week 6 to quantify EE and EI for a professional soccer player of the English Premier League is presented. Over a 10-month period, this case study characterised rates of muscle atrophy and hypertrophy (as assessed by DXA) during a rehabilitation after an anterior cruciate ligament (ACL) injury. In week 6, a specific focus was made on the EE (as assessed by DLW) and EI. Throughout weeks 1-6 the athlete was advised to adhere to a *low CHO-high protein diet* (2-3 $g.kg^{-1}$). In weeks 1-6, total body mass decreased by 1.9 kg, attributable to a 0.6 and 1.2 kg loss in lean and fat mass, respectively. For week 6 the athlete expended 3178 kcals and consumed 2765 kcals on average daily across the 7-day period. In weeks 5-38 the athlete was advised to adhere to a *moderate CHO-high protein diet* (3-5 $g.kg^{-1}$). Throughout this period, the athlete increased his total body mass by 3.9 kg, attributable to a 2.9 and 0.7 kg increase in lean and fat mass, respectively. The athlete successfully completed his rehabilitation and resumed training and matches at first team competitive level with an improved anthropometric and physical profile.

Key Words: carbohydrate, protein, injury, rehabilitation

8.2. INTRODUCTION

Anterior cruciate ligament injuries are common and potentially serious injuries in soccer that often require surgical reconstruction (Brophy et al., 2012). After ACL reconstruction, an athlete's return to play time is between 4 and 9 months (Zaffagnini et al., 2014), thus presenting a long rehabilitation period consisting of a gradual transition through different phases. For example, the initial post-operation recovery phase (i.e. where the athlete is to gain normal symmetrical gait), the progressive loading phase (i.e. where the athlete builds loading in order to commence running), the unilateral load phase (i.e. where the athlete completes outdoor pitch rehabilitation focusing on running mechanics) and the football specific phase (i.e. where the athlete begins to re-integrate into training and match play).

Such phases are likely to be subject to different nutritional requirements. In the initial post operation recovery phase, the athlete is only partly mobile or sometimes completely immobile at the joint (Grant, 2013). This severely restricts the use of the muscle group in the lower limbs and results in a period of muscle disuse. Under such conditions, there is a progressive loss of LBM (Wall et al., 2013), a decline in functional strength (White et al., 1984), a reduction in (local) metabolic rate (Haruna et al., 1994), a decline in insulin sensitivity and increased local fat deposition (Richter et al., 1989).

In a previous case study by our group, it was reported that the rehabilitation of an English Premier League soccer player recovering from ACL surgery and reported a loss of 5.8 kg and 0.8 kg gain in muscle and fat mass in the first 8 weeks of injury, respectively (Milsom et al., 2014). Throughout this period, practitioners commented that it was difficult to provide nutritional recommendations due to lack of knowledge on the athletes daily EE. In order to provide more accurate recommendations for EI, knowledge of the daily EE for a period in the first 8 weeks of rehabilitation from ACL reconstruction would be beneficial to the sports nutritionist.

With this in mind, the aims of this case study were to quantify EE and EI in a player who was undergoing a period of rehabilitation from an ACL injury. To this end average daily EE and daily energy and macronutrient intake were quantified using the DLW and self-reported food diaries (supported by the RFPM and 24 h diet recalls), respectively.

8.3. METHODS

8.3.1. OVERVIEW OF THE PLAYER, INJURY AND SURGERY

The player is a 23-year old male professional soccer player who is internationally capped and currently competing in the English Premier League. At the time of injury, the athlete's physical characteristics were as follows: age, 23 years old; body mass, 77 kg; height 179 cm. The athlete had been a full-time professional player since age 18 and had therefore been engaged in daily structured soccer-specific training for 5 years. He has previously had 2 lateral meniscus tears (both knees) with the current injured knee and the un-injured knee being 4 and 3 years prior to this current injury, respectively. The athlete's muscle injuries were limited to 1 right hamstring tear 1 year prior to injury and at the time of injury the athlete was engaged in daily field-based soccer-specific training, 3 resistance training session per week (1 focusing on lower limbs and 2 focusing on upper limbs) and one-two competitive games per week. The athlete had a training history of 2 resistance sessions per week (both primarily focusing on the lower limbs) for ~7 years.

The athlete presented with a total rupture of the ACL ligament in his left knee. The injury occurred during a *landing motion* in a first team training session. After injury and before the study commenced the player underwent a whole body fan beam DXA measurement scan using the methods outlined in section 3.3. This scan was performed routinely throughout the rehabilitation on weeks 6, 12, 18, 28 and 38 following surgery. Surgery was performed 6 days after injury occurrence and involved surgical ligament repair using a patella tendon graft to replace the damaged ACL. He wasn't immobilised at any point during the rehabilitation although he spent 6 days post operation non-weight bearing.

8.3.2. STUDY DESIGN

Energy expenditure was determined by the DLW methods using the methods outlined in section 3.5. Energy and macronutrient intakes were assessed and analysed using the methods outlined in section 3.6. Assessments of EE and EI were taken during week 6 post injury occurrence as this was within the initial 8-week post-operation recovery phase where it is important to determine EE. An overview of the athletes 'typical day' during week 6 can be found in Table 8.1. The athlete worked each day Monday-Saturday in the working week with Sunday (Day 5) used as a day off. The study was conducted according to the requirements of the Declaration of Helsinki and was approved by the university ethics committee of Liverpool John Moores University.

Table 8.1. An overview of a typical days rehabilitation program which the athlete underwent during the assessment week

Time	Activity
08:30	Upper Body Cardiovascular
09:00	Breakfast
10:00	Electrotherapy
10:30	Gym-lower limb strength
12:00	Lunch
13:00	Gym-upper limb strength
14:00	Gym-core
14:30	Hydrotherapy
15:00	Soft Tissue Therapy
15:30	Physiotherapy

8.4. RESULTS

8.4.1. QUANTIFICATION OF ENERGY AND MACRONUTRIENTINTAKE

An overview of the players' typical daily food consumption and a comparison of daily energy and macronutrient intake are presented in Table 8.2 and Figure 8.1., respectively. On average the players' EI and EI relative to LBM were 2765 kcals (range=2286-3626 kcals) and 45.5 g·kg^{-1} LBM (range=37.6-59.6 g·kg^{-1} LBM).

Additionally, his average daily absolute and relative CHO intake was 181 g (range=141-239 g) and 2.4 $g\cdot kg^{-1}$ (range=1.9-3.2 $g\cdot kg^{-1}$), protein intake was 201 g (range=128-245 g) and 2.7 $g\cdot kg^{-1}$ (range=1.7-3.3 $g\cdot kg^{-1}$) and fat intake was 141 g (range=108-201 g) and 1.9 $g\cdot kg^{-1}$ (range=1.4-2.7 $g\cdot kg^{-1}$).

8.4.2. ENERGY AND MACRONUTRIENT DISTRIBUTION ACROSS MEALS

Absolute and relative energy and macronutrient intakes across meals are displayed in Figure 8.2. Both absolute and relative intakes are greater at Dinner and Lunch compared with Breakfast and Snacks. Additionally, all macronutrients (both absolutely and relative) follow a similar pattern with the macronutrients being unevenly distributed in the hierarchical order Dinner >> Lunch >> Breakfast >> Afternoon Snack >> Evening Snack >> Morning Snack.

8.4.3. ENERGY EXPENDITURE VS. ENERGY INTAKE

The average daily EI and EE along with any subsequent body mass changes over the rehabilitation period can be found in Figure 8.3. On average the player was consuming 2765 kcals and expending 3178 kcals, giving an average daily deficit of 413 kcals. Over the weekly micro-cycle the player subsequently lost 0.5 kg in body mass.

8.4.4. ANTHROPOMETRIC DEVELOPMENTS OVER THE REHABILITATION

Changes in total body mass, lean mass and fat mass over the course of the full rehabilitation and delta changes throughout each period are presented in Figures 8.4 A-H and 8.5 A-D. During weeks 1-6, total body mass decreased by 1.9 kg that was attributable to 0.6 kg and 1.2 kg of lean and fat mass losses, respectively. It is noteworthy that during this period the major contributor to lean mass loss was through the lower limbs with the players' left (injured leg) and right reducing by 0.9 kg and 0.6 kg, respectively (see Figure 8.5.). There was also some small loses of 0.1 and 0.4 kg in both left and right leg fat mass, respectively. The majority of these losses in body mass were offset by a 0.7 kg increase in trunk lean mass (see Figure 8.4.).

After the initial post-operation recovery phase, the player slowly began to increase total body lean mass with hypertrophy in the lower limbs progressing back to pre-injured values by week 28. Due to increases in arm (see Figure 8.6.) and trunk lean masses across the rehabilitation the total lean mass gains were 2.3 kg with a total fat mass loss of 0.5 kg.

Table 8.2. An overview of a typical days food consumption during the assessment week (Day 6)

Meal/Time	Item and Description	Amount (g)*
Pre Breakfast Snack (08:00)	Latte	260
Breakfast (09:00)	Eggs (Scrambled)	180
	Smoked Salmon	60
	Spinach	10
	Greek Yoghurt	170
	Mixed Nuts	20
	Honey	28
Lunch (12:00)	Chicken Breast in Breadcrumbs	300
	Mixed Salad with Olive Oil Dressing	200
	Peppers Mixed	20
	Sweetcorn	47
	Balsamic Glaze	15
Afternoon Snack (15:00)	Latte	260
	Protein Bar	55
Dinner (19:30)	Roasted Lamb	120
	Broccoli	76
	Carrots	35
	Parsnips	42
	Greek Yoghurt	
	Raspberries	
	Totals	
	Energy (kcal)	**2679**
	Carbohydrate (g)	**150**
	Fat (g)	**144**
	Protein (g)	**205**

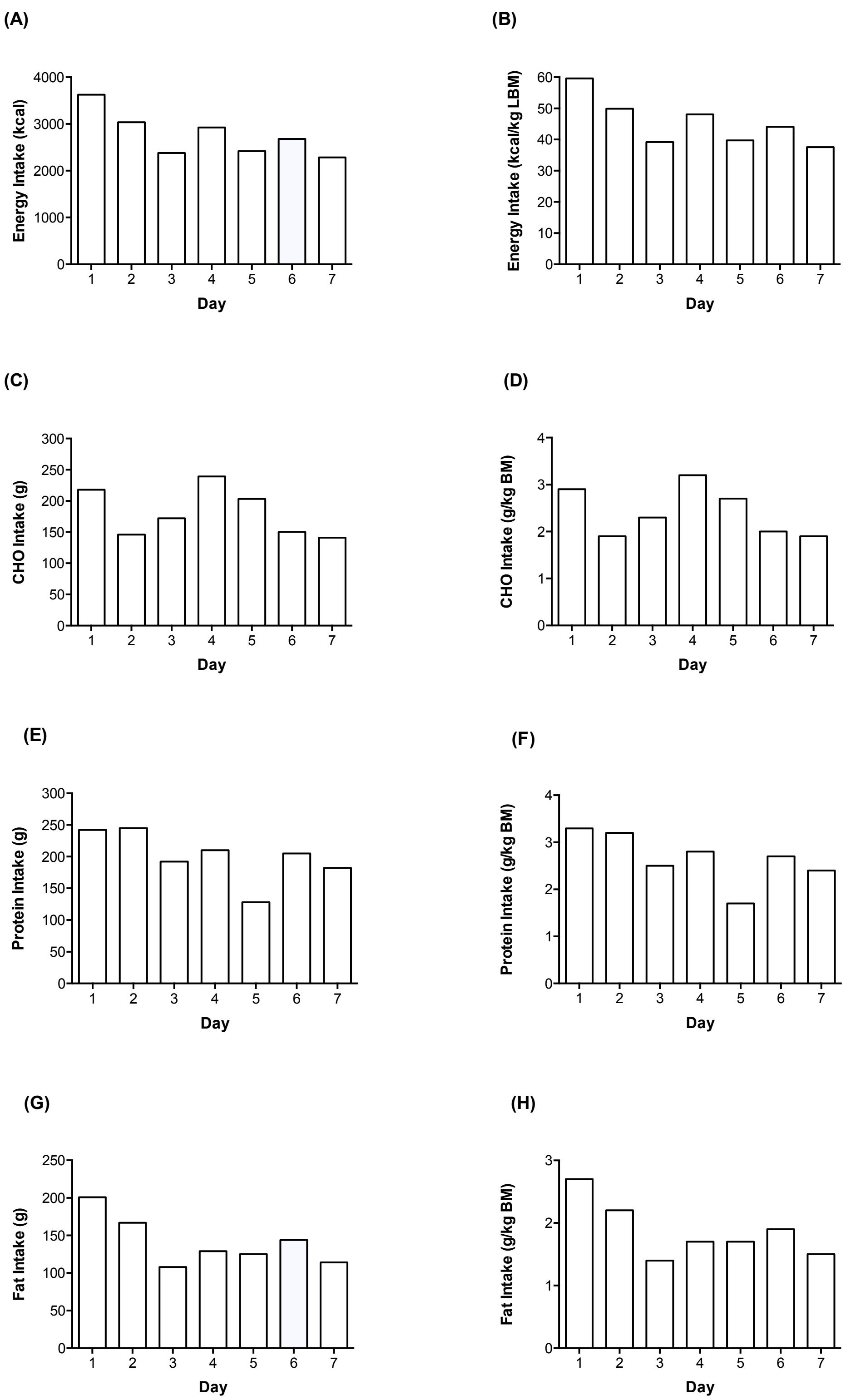


Figure 8.1. Daily energy and macronutrient intake expressed absolutely and relative to body mass over the 7-day testing period. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat.

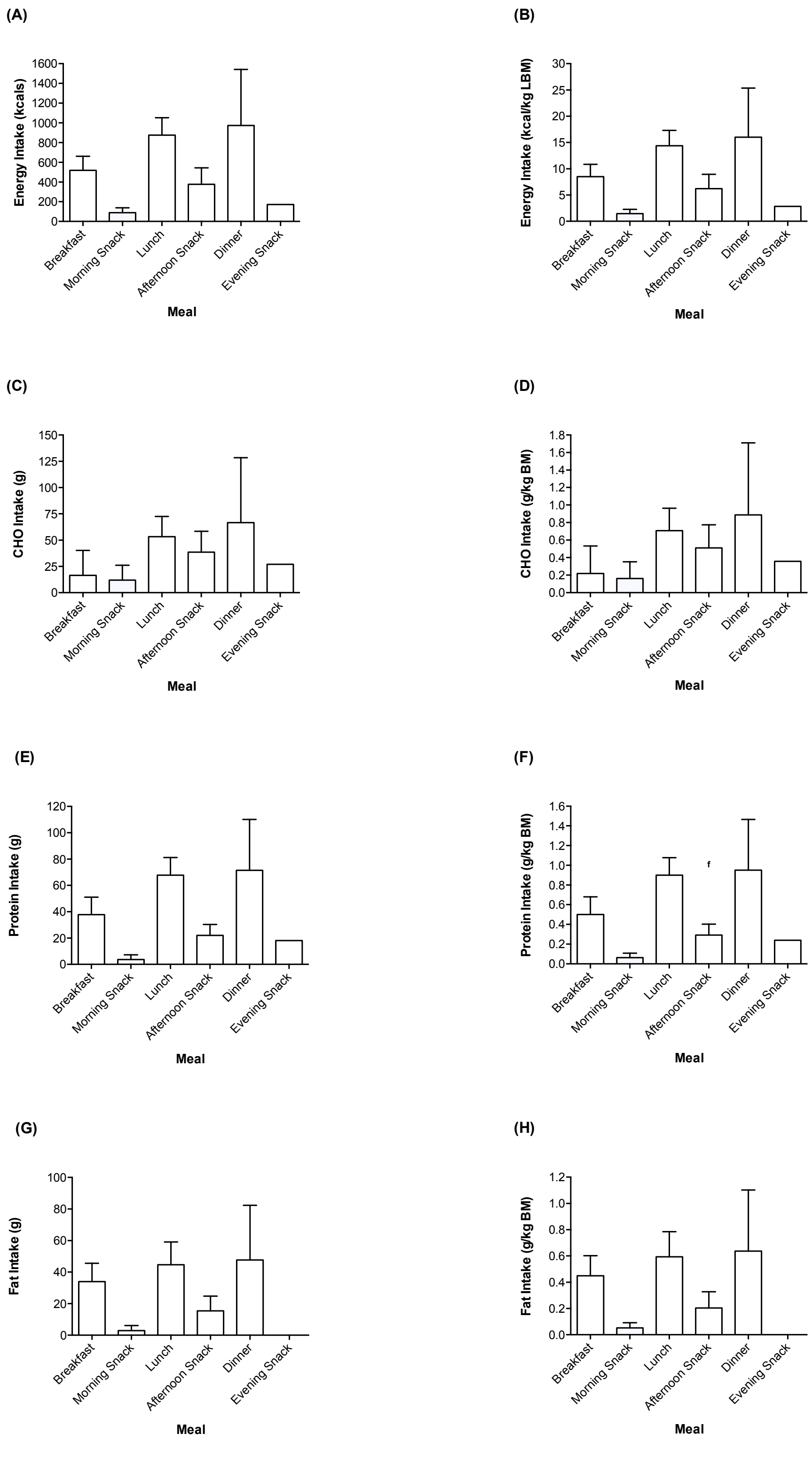
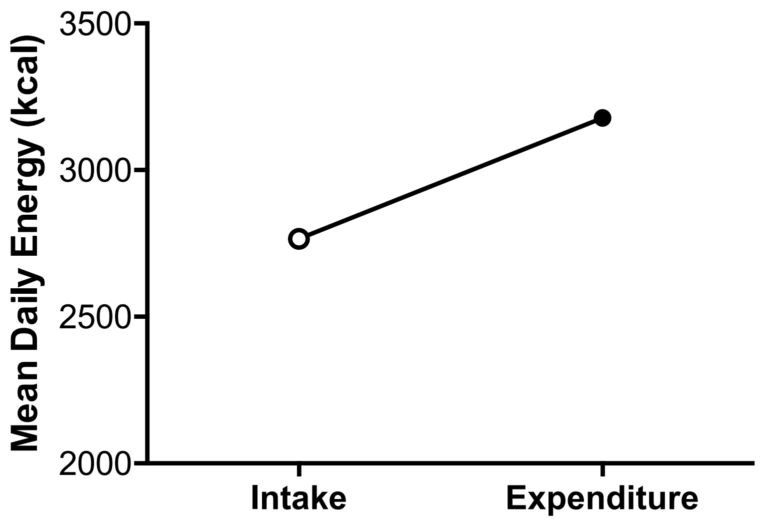


Figure 8.2. Energy and macronutrient intakes meal distribution on training days. Figure A=absolute energy intake, Figure B=energy intake relative to lean body mass, Figure C=absolute carbohydrate, Figure D=relative carbohydrate, Figure E=absolute protein, Figure F=relative protein, Figure G=absolute fat and Figure H=relative fat.

(A)



(B)

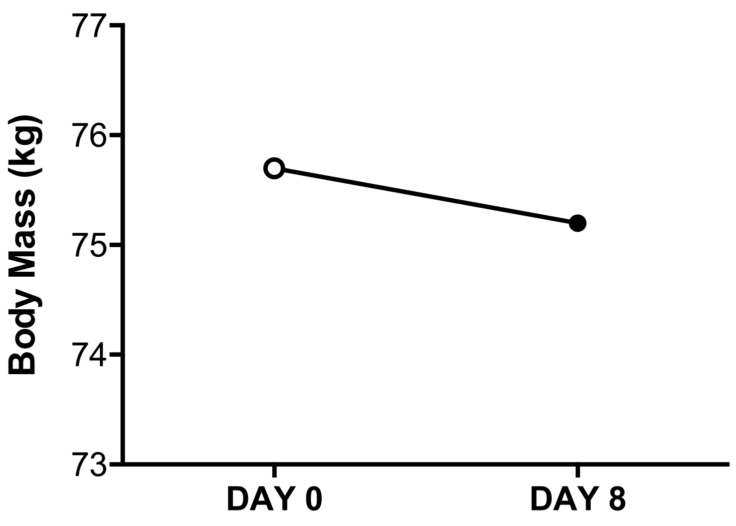


Figure 8.3. Differences in average daily energy intake vs. average daily energy expenditure and body mass changes from day 0 to day 8. Figure A=energy intake vs. energy expenditure and Figure B=body mass changes.

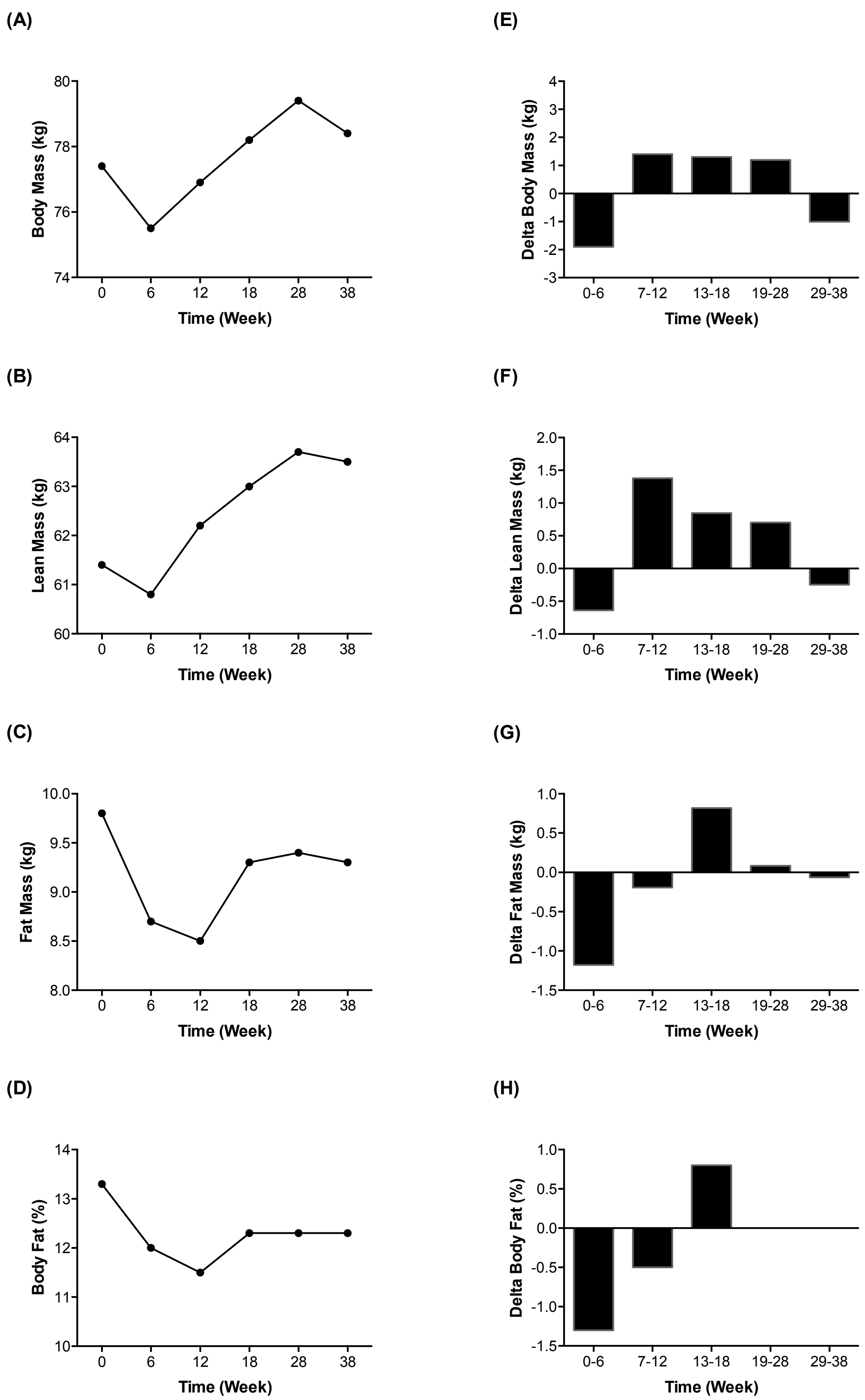


Figure 8.4. Changes in total (A) body mass, (B) lean mass, (C) fat mass and (D) fat percentage. Changes in body mass (E), lean mass (F), fat mass (G) and fat percentage (H) expressed as delta change during the specific period highlighted.

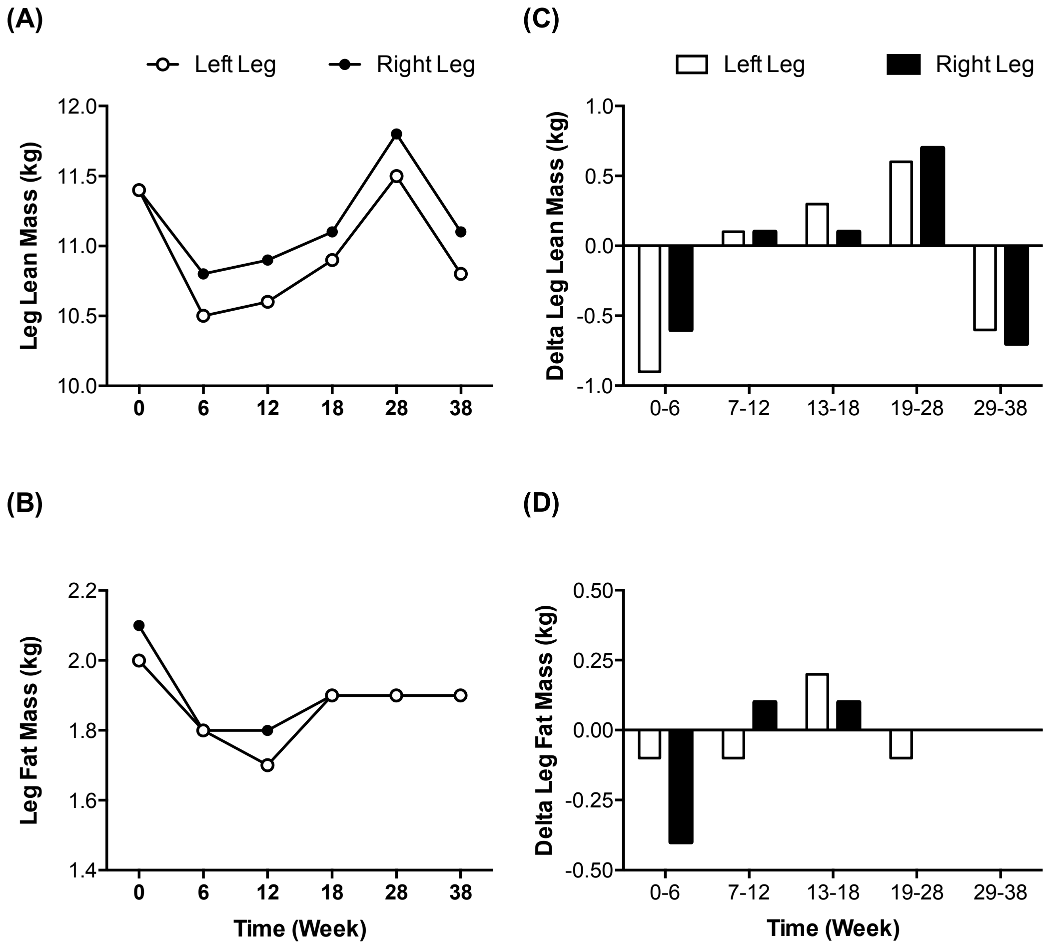


Figure 8.5. Changes in total (A) leg lean mass and (B) leg fat mass. Changes in leg lean mass (C) and leg fat mass (D) expressed as delta change during the specific period highlighted. Left leg = injured leg and right leg = uninjured leg.

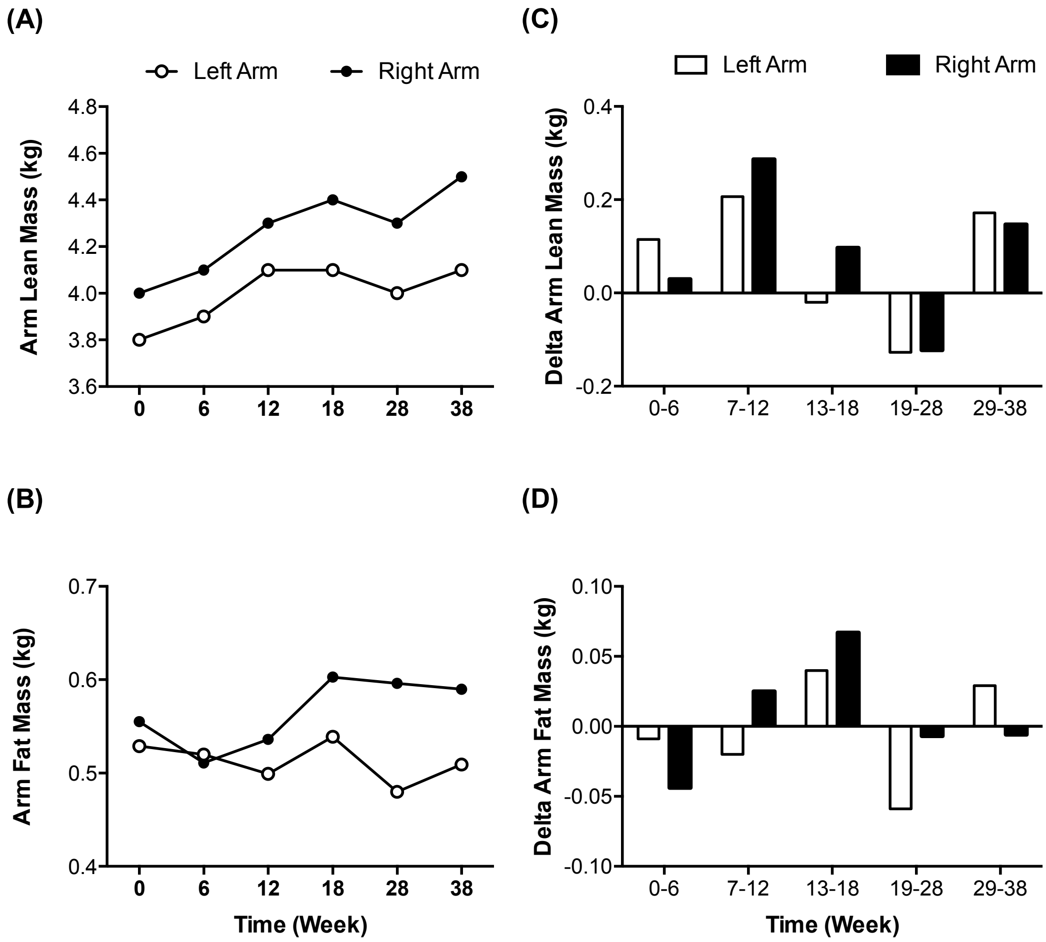


Figure 8.6. Changes in total (A) arm lean mass and (B) arm fat mass. Changes in arm lean mass (C) and arm fat mass (D) expressed as delta change during the specific period highlighted.

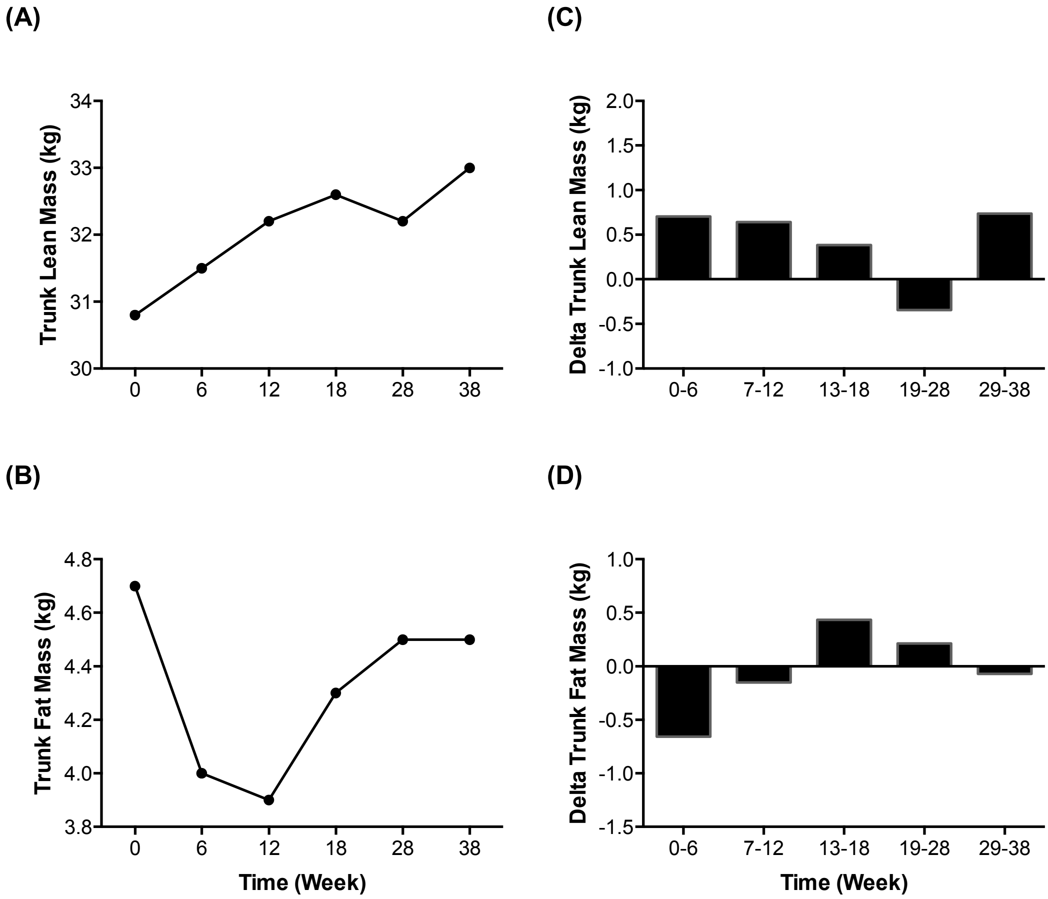


Figure 8.7. Changes in total (A) trunk lean mass and (B) trunk fat mass. Changes in trunk lean mass (C) and trunk fat mass (D) expressed as delta change during the specific period highlighted.

8.5. DISCUSSION

The aim of the present case study was to simultaneously quantify EI and EE across a 7-day period in a player from the English Premier League who was undergoing a rehabilitation period from an ACL injury. In order to study a difficult period of rehabilitation from a nutritional perspective, a player at 6 weeks post ACL injury was studied. This is the first to report direct measurements of EE (using the DLW method) in an elite English Premier League Player undergoing a period of rehabilitation. These data therefore provide a reference point for which to formulate nutritional and energy intake guidelines for players undergoing long-term rehabilitation programmes.

The mean daily EI and EE data reported here suggest that this player was completing this period of rehabilitation in an energy deficit. As such, a loss of both lean and fat mass during the initial 6-week period (see Figure 8.4.) was observed. Additionally, over the 7-day period of energy intake and expenditure assessment the athlete experienced a -0.5 kg loss on body mass. It is notable that this player has less EI (2765 vs. 3186 ± 367 kcals) and expenditure (3187 vs. 3566 ± 585 kcals) than players from the same team in outfield positions that are regularly training and playing (Anderson et al., 2017; Chapter 6). Therefore, it is clear that players undergoing a period of rehabilitation are required to subsequently alter their nutritional intake.

With regards to the players' body composition changes, the largest rates of atrophy were observed in the initial 1-6 weeks post injury. This is similar to the increased muscle atrophy in this period observed by this group previously (Milsom et al., 2015) and also the large atrophy rates observed in randomised controlled trials (Wall et al., 2013). Indeed, in the case study on a player from the same team, there was a lean mass loss of 5.8 kg which was attributable to a 3.8 kg loss in trunk mass and a 1.4 and 0.8 kg loss in the injured and non-injured legs respectively (Milsom et al., 2014). In the present study, there was a lean mass loss of 0.6 kg that was attributable to an increase of 0.7 kg in the trunk lean mass and a decrease 0.9 and 0.6 kg in the injured and non-injured leg, respectively. Such differences between studies are likely due to the different energy intake consumed by each player e.g. the player here reported higher energy intake (2765 kcals) than that previously (1970 kcals) (Milsom et al., 2014). Additionally, in the present case study the player was also undergoing load (see Table 8.1.) (albeit was non-weight bearing for the 5 days post surgery) from immediately after the surgical operation, whereas in Milsom et al. (2014) the player was completely immobilised for the initial 4-weeks post surgery and limited to 90° flexion for the 4-weeks after. Additionally, the player in the present study was undergoing structured upper and lower body strength programs within week 1 of rehabilitation although detailed loading data on this period is not presented in the present case study. It is likely that both the nutritional and training alterations in the present case study are likely contributors to the reduced loss in lean body mass. Therefore, restrictions in programming in the initial stages after injury along with any energy restrictions are likely to have a significant influence on the body composition changes during this time.

In addition to the differences in energy intakes and training programmes post surgery, the player in the present study had slightly higher CHO (2.4 vs. 1.8 $g.kg^{-1}$) and protein (2.7 vs. 2.5 $g.kg^{-1}$) intakes than previously reported (Milsom et al., 2014). The high protein intakes reported here (e.g. 2.7 $g.kg^{-1}$) are likely to be extremely important during an energy deficit given previous data that high protein intakes can attenuate the loss of lean mass (Churchward-Venne et al., 2013). However, protein intakes were similar to that of Milsom et al. (2015) during the initial phase and it is likely that the reduced energy deficit (as achieved via increased CHO intake) and the structured upper and lower body resistance programs all contributed to the attenuated lean body mass in the trunk and arms, and also minimised loss in the lower limbs.

As discussed previously, the initial post operation recovery phase is crucial in minimising lean body mass loss and fat mass gain in the athlete. However, if this period is successfully completed, then further, more progressive gains can be made in the periods after in order to 1) continue to develop physical and anthropometric qualities beyond pre injury condition and 2) aid the rehabilitation from injury with the strengthening of the lower limbs, more importantly the injured limb. It is demonstrated here a progressive increase in both lean muscle mass whilst minimising fat mass loss. However, it is acknowledged that further information on each phase of this rehabilitation is beyond the scope of this study and provides a fruitful area for more research.

Despite the novelty and practical aspects of the current study, our data are not without limitations, largely a reflection of the practical demands of data collection in an elite football setting. Most limitations have been mentioned in this thesis previously (Chapter 6). Additionally, although an overview of load is provided during the study, due to the large volumes of different work the player is undergoing, it is difficult to quantify work exactly. Also, only one microcycle is provided and in order to have an understanding of the energy demands during the full rehabilitation period, this study would have to be replicated at numerous stages throughout the rehabilitation process. Of particular interest would be during the initial 2-weeks post injury although this is logistically difficult in the applied setting. Furthermore, unlike traditional randomised controlled trials incorporating large sample cohorts, this study provided a ‘real world’ example of one player only and hence data are limited to the specific context of this injury and rehabilitation programme.

8.6. CONCLUSION

In summary, this study simultaneously quantified for the first time, the daily energy and macronutrient intakes and average daily EE of an elite professional soccer player undergoing a period of rehabilitation from an ACL injury. Our data confirm the role of energy availability and physical loading in minimising rates of muscle atrophy during the initial eight weeks following ACL reconstructive surgery.

CHAPTER 9

SYNTHESIS OF FINDINGS

9.1. SYNTHESIS OF FINDINGS

The purpose of the following chapter is to provide an overview of the conceptual and theoretical interpretation of the data arising from this thesis in relation to the aims and objectives outlined in Chapter 1. A general discussion is presented where specific attention is given to how the present data has advanced out understanding of the training load and energy requirements of professional soccer. Finally, a review of limitations of the experimental chapters is presented followed by recommendations for future research.

9.2. ACHIEVEMENT OF THE AIMS AND OBJECTIVES

The primary aim of the present thesis was to quantify the physical loading (both training and match play), EE and EI of elite professional soccer players from the English Premier League. On the basis of characterising the habitual loading patterns and typical EE, a secondary aim was to formulate contemporary nutritional guidelines in accordance with the concept of nutritional periodisation. If the aims of the thesis were achieved, it was proposed that data from this thesis would assist sports scientists, sports nutritionists and soccer players themselves to make more informed decisions about nutrition and training requirements in order to improve overall performance and recovery. The aims of this thesis were achieved through the completion of 5 inter-linked studies (Chapters 4, 5, 6, 7 and 8).

Aim 1

To quantify training and match load during different weekly micro-cycle scenarios in an English Premier League Team (Study 1, Chapter 4).

The physical and nutritional demands of soccer match play have long been known. However, research on absolute training loads in professional soccer is limited and training load data related to the variations in fixture schedules are likely to further complicate nutritional requirements. It is therefore considered a difficult task by the nutritionist to provide nutritional recommendations for training demands and that of different fixture schedules. The data presented in this chapter demonstrated that daily training load and weekly-accumulated load (reflective of both training and match demands) during one-, two- and three-game week schedules show marked differenced within- and between-game schedules. As such, these data have implications for the nutritional strategies that should be implemented in different micro-cycles of the season. Specifically, the data from Study 1 suggested that CHO should be manipulated according to the physical demands of the weekly micro-cycle.

Aim 2

To quantify training and match load over the course of an entire competitive in season and examine the differences in load between groups of players who are categorised into starting status (Study 2, Chapter 5).

Having identified the typical daily load occurred by 'starting' players in Study 1, the aim of Study 2 was to quantify any differences in load that could occur in players with different starting status. By categorising players into 3 groups of starting status and monitoring their accumulative load over the entire season, the data suggest that total seasonal volume of training (i.e. total distance and duration) remained similar between groups. However, seasonal high-intensity loading patterns are dependent on players' match starting status. These data demonstrate the importance of training program design between individuals across an entire season in order to give comparable seasonal workloads across groups.

Aim 3

To quantify training load, match load, EE and EI of English Premier League players during a typical in-season micro-cycle (Chapter Study 3, Chapter 6)

Given the apparent fluctuations in daily training load observed in Study 1 it was suggested that EE may vary accordingly and hence, EI could also be adjusted to account for the goals of that particular day. The data presented in this chapter demonstrated a weekly overview of the habitual CHO periodisation strategies that are used by an English Premier League team. Additionally, the EE of Premier League soccer players was quantified for the first time. Ultimately, these data suggest that whilst CHO intake may be suitable to meet the energy requirements on training days, players do not appear to meet current CHO guidelines for preparation for and completion of soccer match play.

Aim 4

To quantify EE and EI in English Premier League players undergoing different situations than typical starting outfield players (Chapters 7 and 8).

Given that Study 1, 2 and 3 focused on outfield players, Study 4 and 5 utilised case-study design to quantify the physical load, energy intake and energy expenditure in a professional GK and an injured player undergoing long-term rehabilitation from an ACL injury. Importantly, these data highlight differences in energy requirements from outfield players and therefore provide a platform for which to formulate specific nutritional guidelines for two special populations.

9.3. GENERAL DISCUSSION OF THE FINDINGS

9.3.1.1. EFFECTS OF MATCH SCHEDULE ON LOADING

The physical demands of soccer match play have been studied in extensive detail for over four decades (Reilly & Thomas, 1976; Di Salvo et al., 2006; Di Salvo et al., 2009; Russell et al., 2016). During this period, researchers have tended to examine the effects of different situational variables of match play on physical performance including player position (Bradley et al., 2009; Bradley et al., 2011; Bloomfield et al., 2007; Di Salvo et al., 2007; Mohr et al., 2003), playing formation (Bradley et al., 2011), playing standard (Bradley et al., 2013) and era (Barnes et al., 2014). Such research has allowed sport scientists to devise specific training and nutritional guidelines for match play based on the players' physical profile. For example, central midfielder's cover the most total distance in the team (Bloomfield et al., 2007) and wide midfielders and wide defenders cover a greater amount of high speed running and sprinting (Bradley et al., 2009) potentially leading to a greater dependence on CHO availability in preparation, during and in recovery from match play.

In contrast to the match demands, the physical demands of training in elite players have only recently started to be examined. Reasons for this are potentially due to the only recent advances and rise of GPS technology in team sports (Cummins et al., 2012; Dellaserra et al., 2014; Scott et al 2016). Prior to completion of this thesis, research on training load in professional soccer has produced an examination of average values over a 10-week period (Gaudino et al., 2013), absolute values over a single week exposure (Owen et al., 2014), a season long analysis into periodisation strategies used by an elite club (Malone et al., 2015), a congested fixture period (Morgans et al., 2015) and most recently, average values (and ranges) over the season for each day when one game per week was being played (Akenhead et al., 2016).

Although the absolute and habitual loads undertaken by soccer players are starting to become clearer, numerous situational variables are likely to also affect the training load, and thus the nutritional requirements. In Chapter 4 of this thesis, both training and match load during three different weekly game schedules were examined. Players were monitored in training and matches over a one (Saturday-to-Saturday), two (Sunday-to-Saturday) and three game per week (Sunday-Wednesday-Sunday) fixture schedule. Our findings demonstrate that training load is significantly less than match load even in a one game per week schedule (see Figure 4.1.). Additionally, in the two game per week schedule the addition of a competitive match at the start of the week only reduces the load experienced on day 3 (match day +2) although the absolute volume and distance covered at high intensity are more augmented from the one game per week. This however, should not change much of the implications for CHO periodisation and similar strategies can be evident for both weeks. Therefore, strategies should aim at enhancing recovery (Gunnarsson et al., 2013; Krustrup et al., 2011), optimizing adaptations through manipulating CHO availability in order to promote training adaptations (Bartlett et al., 2015), maintaining desired body composition (Milsom et al., 2015; Morton et al., 2010) and promote muscle glycogen storage in the days and hours before competition (Krustup et al., 2006). In the three game per week schedule, the increase in match frequency significantly increased player's exposure to increased volume and work in high-intensity speed zones (see Figure 4.2). Additionally, given there is only 2 days between competitive matches, CHO intake should be high on each day of the micro-cycle in order to optimally fuel match play and promote recovery after match play cessation (Krustrup et al., 2006; Gunnarsson et al., 2013; Krustup et al., 2011).

Given the increased time between fixtures, the one- and two- game per week schedules lend themselves to the concept of CHO periodisation. In doing so, strategies should aim at manipulating the CHO intake by "fuelling for the work required", previously suggested as a framework for endurance athletes (Impey et al., 2016). In this regard, such strategies are intended to concomitantly promote components of training adaptations (e.g. activation of regulatory cell signaling pathways) but yet, also ensure adequate CHO and energy availability to promote competitive performance, reduce injury risk and aid recovery (Burke et al., 2011; Chamari et al., 2012; Burke et al., 2006).

9.3.1.2. EFFECTS OF STARTING STATUS

Evidence of the methodological manipulation of training load in the recovery from and in the build up to a competitive fixture illustrate the importance of the match to the overall planning and preparation strategies used within soccer (Malone et al., 2015). It is noteworthy of the dominant role which match play appears in the weekly micro-cycle and is typically associated with the highest physical load (Anderson et al., 2015; Chapter 4). This is the case for parameters such as total distance (e.g. < 7 km v ~10-13 km) (Bangsbo et al., 2006), high-speed running distance (e.g. < 300 m v > 900 m), sprinting distance (e.g. < 150 m v > 200 m) (Di Salvo et al., 2010) and average speed (e.g. < 80 m/min v ~100-120 m/min (Anderson et al., 2015, Chapter 4). Although the typical current training practices of professional players may be sufficient in order to promote recovery and readiness for the next game (thus reducing risk of over-training and injury), it could also be suggested that it is the participation in match play itself that is the most appropriate stimulus for preparing players for the physical demands of match play. This point is especially relevant considering previous evidence demonstrating significant positive correlations between individual in season playing time and aspects of physical performance including sprint performance and muscle strength (Silva et al., 2011). More recently, Morgans et al. (2017) demonstrated evidence of improved counter movement jump height being proportional to the amount of high-intensity distance covered in match play itself. Therefore, it is evident that match play is a potent stimulus in the development of physical qualities associated with soccer.

To give a practical overview of the situation in a professional team from the English Premier League, a playing squad consists of ~22 outfield players, ~12 players often go without this match stimulus during the weekly micro-cycle, with a maximum of 3 players coming on as substitutes. Therefore, these players are not experiencing the same loads to that of players comprising the starting 10 outfield players. Such situations have obvious implications for both training load scheduling and nutritional intake. In Chapter 5 of this thesis, outfield players from the English Premier League were monitored over an entire in season period and classified players as starters (>60% of games), fringe players (30-60% of games) or non-starters (starting <30% of games). Our findings indicated that the starting status had no apparent effect on total volume (duration and total distance) completed over the season. Perhaps more important, however, was the observation of significant differences in the pattern of activity completed in high intensity speed zones which players are often far away from in training itself (Anderson et al., 2015; Chapter 5). In this regard, it is acknowledged that starters generally completed more distance in running, high-speed running and sprinting speed zones than both fringe and non-starting players. Additionally, this was largely due to time spent in the game itself as opposed to differences in training load patterns.

Given the role of high intensity training in promoting soccer-specific match fitness (Iaia et al., 2009; Bangsbo, 2008; Dupont et al., 2004; Wells et al., 2014), the role of match time exposure on key physical performance characteristics associated to soccer (Silva et al., 2011) and the role of high-intensity distance providing a physiological stimulus for muscular power (Morgans et al., 2017), soccer players training load is likely to be different depending on whether they're starting regular fixtures or not. Therefore, soccer players who are not receiving sufficient match playing time should have altered training load to include more emphasis on recreating the high intensity demands of match play. The practical implications of the differences in load over starting status are important for the evaluation and re-designing of training programs in order to maintain overall squad physical fitness and game readiness. Undeniably the distances covered in the high intensity zones during games display strong associations to physical capacity (Krustrup et al., 2003; Krustrup et al., 2005) and thus, if a player is not consistently exposed to these loads in the weekly micro-cycle and over the course of a season, then players who aren't exposed to game time may present with a detraining effect over a season (Silva et al., 2011). The completion of such high intensity load, even at the expense of total physical work done is both sufficient and necessary to activate the molecular pathways that regulate skeletal muscle adaptions related to both aerobic (Egan et al., 2010; Gillen & Gibala, 2014) and anaerobic (Iaia et al., 2008) performance. Additionally, when those players classified as fringe or non-starters are then required to start a match, a potential for injury exists due to the necessity to complete uncustomary loading patterns (Malone et al., 2017b; Gabbett, 2004). However, higher levels of chronic training loads (previous 21 days) and higher levels of intermittent aerobic fitness reduce the injury risk associated with these distances in soccer players (Malone et al., 2017b). Training strategies that 'mimic' the external demands of match play have recently been established and could be a potential training tool to use with players the day of or after a competitive game in order to provide a significant match stimulus (Lacome et al., 2017).

9.3.1.3. EFFECTS OF POSITIONAL STATUS

On an individual basis, load can often become complex and lead to complications in load management such as that of each players positional and tactical role in the team. Researchers have long identified positional differences in soccer match play (Bradley et al., 2009; Bradley et al., 2011; Bloomfield et al., 2007; Di Salvo et al., 2007; Mohr et al., 2003). In training, initial research observed positional differences in the outfield playing squad (Malone et al., 2015). It was reported that central midfielders and wide defenders covered the highest total distance with central defenders displaying the lowest values. Additionally, wide midfielders also tended to cover greater high intensity distance than central defenders. More recently, Akenhead et al. (2016) demonstrated positional differences in training load for another team. Similarly, central midfielders covered were reportedly ~8-16% greater total distance than central defenders, wide defenders and forwards. However, in this study, no differences in high intensity distance were evident between positions. In the present thesis, Anderson et al. (2015; Chapter 4) presented differences between positions for total distance with wide defenders, central midfielders and wide attackers covering greater distance than central defenders and attackers, although it must be stressed that no statistical tests were run on this data due to the small sample size. Additionally, although data weren't reported in this chapter, wide defenders, wide attackers and attackers covered greater distance at high intensity during the one- game week training than central defenders and central midfielders. This was particularly evident on day 4 where the training load was at its highest and training was performed with large numbers (e.g.. 10v10), large pitch sizes (e.g. 75x60m) and long durations (i.e. 2x15 minutes). These types of training sessions often encompass players in game like situations performing actions like they would in competitive match play. Additionally, in data collected but not presented in Anderson et al., (2015; Chapter 4), on days like day 3 where training content consists of low numbers (e.g. 5v5), small pitch sizes (e.g. 30x25m) and short duration (e.g. 2-3 minutes) then no real positional differences were observed. Such data is reflective of that suggested before (Morgans et al., 2014) and illustrate the role of different managerial and coaching structure in the overall training process and outcome. An area for future research exists in examining the positional differences of training in soccer players, which could allow further individualization of training and nutritional programs.

Outfield players have dominated the small amount of training load research to date and very little is known about current load endured by elite level GKs during training. Considering the GKs importance to the team, this is very surprising and offers fruitful areas of research and examination. In competitive matches the GK covers significantly less distance (5611 ± 613 vs. 10841 ± 950 m) and distance in high intensity speed zones (>19.8 km · h^{-1}) than their outfield teammates (56 ± 34 m vs. 980 ± 294 m) (Di Salvo et al., 2008; Bradley et al., 2010). However, it is understood that the demands of a GK are assessed on their ability to perform high-intensity movements and explosive actions, which are separated by longer walking and jogging periods that allow for recovery (Ziv & Lidor, 2011). Professional soccer clubs that employ specific GK coaches to work their players often train separately from the rest of the team for the majority of the session. Therefore, it is likely that GK different training loads than outfield players.

In Chapter 7 of this thesis, an elite GKs training and match load over the course of a typical weekly in season micro-cycle was monitored. For the first time, key parameters of physical loading were reported for GK during training sessions, some of which were remarkably similar to the outfield positions loads during the same competitive week such as total distance (2422 m vs. 2865 m) and high intensity distance (0 m vs. 32 m) (Anderson et al., 2017; Chapter 6). However, such loads were observed in a two game per week fixture schedule (Thursday-Sunday) and are likely to differ greatly to the outfield players when the physical emphasis is not on recovery and preparation for the upcoming fixture (Nedelec et al., 2015). Indeed, it is important to understand such typical training load values for GKs, as well as specific movement functions such as the ability to produce high intensity and explosive movements such as jumping, diving and returning from a dive. Until recently, such variables could not be recorded during training sessions, but now a recent development of GK specific algorithms in GPS units have allowed for day to day collection. However, such devices are yet to be validated in scientific research and thus, are unable to be published in this thesis. An interesting and valuable area for future research would be to validate and publish the training and match demands of elite soccer GKs.

9.3.2. ENERGY REQUIREMENTS OF SOCCER PLAYERS

9.3.2.1. ENERGY EXPENDITURE

Given the daily fluctuations in training load reported in Study 1, energy expenditure may vary accordingly. Such knowledge of fluctuations in energy expenditure would allow energy intake to be adjusted to account for the goals of that particular day. The concept of "fuelling for the work required" has recently been suggested as a practical framework for which to apply nutritional periodisation strategies to endurance athletes (Impey et al., 2016). This framework encompasses strategies which are intended to concomitantly promote components of training adaptation (e.g. activation of regulatory cell signaling pathways) but yet, also ensure adequate CHO and energy availability to promote competitive performance, reduce injury risk and aid recovery (Burke et al., 2011; Chamari et al., 2012; Burke et al., 2006). Despite such theoretical rationale, it is difficult to prescribe accurate nutritional guidelines for professional soccer players. Prior to this thesis, only one study has provided direct assessments of EE in the modern professional adult player who found that players competing in two competitive fixtures per week expended 3532 ± 408 kcals on average per day (Ebine et al., 2002). However, this study was performed on professional Japanese players and is not considered reflective of a team competing in the English Premier League and European Competitions.

In order to provide direct assessments of EE, players are required to be monitored in free-living conditions. Assessments of EE can be done using the DLW method while avoiding any interference with training activities (Montoye et al., 1996). However, a limitation of the DLW technique is the inability to provide day-to-day EE assessments. Therefore, in Chapter 6 of this thesis EE was monitored over a 7-day in season period that consisted of two match days and 5 training days in elite players from the English Premier League. Average daily EE of 3566 ± 585 kcals were reported, similar to that of Japanese players (Ebine et al., 2002). This can allow us to design specific average daily guidelines over a competitive week in order to create an equal, positive or negative energy balance, maximise recovery, adaptation and preparation for the next competitive fixture.

9.3.2.2. ENERGY AND MACRONUTRIENT INTAKE

If the energy requirements of soccer players are known, the knowledge of current nutritional intakes are key in order to alter intakes accordingly. Nutritional assessments of soccer players have primarily focused around the elite youth population with very few studies conducted in the senior elite professional player (see Table 2.2.). Most recently, Bettonviel et al. (2016) studied energy and macronutrient intakes across different days in elite Dutch players. Additionally, energy and macronutrient intakes have been examined in players from the United Kingdom two decades ago (Maughan, 1997) and more recently, CHO and protein intake have been reported in players from the English Football League (Ono et al., 2012). One of the key conclusions from these studies is that protein has subsequently increased over eras which is potentially driven by the increased scientific research and resulting athlete (and coach) awareness of the role of protein in facilitating adaptations and recovery from both aerobic and strength training (Moore et al., 2014; McNaughton et al., 2016). However, information was unclear about nutritional practices of players from an elite club in the English Premier League who were operating on a two game per week schedule.

In order to better understand the current nutritional practices of soccer players from the English Premier League, Chapter 6 of this thesis examined the habitual nutritional intakes over a 7-day in season period where two competitive matches were played. A similar EI of 3186 ± 367 kcals to those reported in Japanese players 3113 ± 581 kcals was observed (Ebine et al., 2002). Additionally, evidence of CHO periodisation in accordance with upcoming physical load and likely differences in day-to-day EE was also observed. Both absolute and relative daily energy and CHO intake was greater on match days (3789 ± 532 kcal and 6.4 ± 2.2 $g.kg^{-1}$, respectively) compared with training days (2948 ± 347 kcal and 4.2 ± 1.4 $g.kg^{-1}$, respectively). Therefore, it is suggested that soccer players who are competing in two competitive matches per week are not consuming adequate CHO to optimise muscle glycogen storage in the day before and in recovery from games (Bussau et al., 2002; Krustrup et al., 2006). This is especially relevant considering the inability to fully replenish muscle glycogen content in type II fibers 48 hr after match play, even when CHO intake is > 8 g.kg^{-1} body mass per day (Gunnarsoson et al., 2013).

Additionally, players reported higher daily protein intakes (205 ± 30 g) than reported two decades ago in British professional players (108 ± 26 g), whereas both CHO and fat intakes were relatively similar (Maughan, 1997). However, our daily protein intakes agreed with those reported more recently (150-200 g) in adult professional players from the Dutch league (Bettonviel et al., 2016). As aforementioned, differences in protein intakes between eras are potentially driven by the increased scientific research and resulting athlete (and coach) awareness of the role of protein in facilitating training adaptations and recovery from both aerobic and strength training (Moore et al., 2014; McNaughton et al., 2016). The data from Chapter 6 of this thesis gives practitioners areas to significantly improve quantity of CHO intakes on training days and also different areas of macronutrient intakes such as the quantity and timings of feedings, often called the distribution of macronutrient intakes. The data from this Chapter has allowed us to develop nutritional targets for players to achieve on both training and match days in order to improve current CHO feeding practices.

9.3.2.3. ENERGY AND MACRONUTRIENT DISTRIBUTION

Further to the quantification of daily energy and macronutrient intake, it is also important to consider the daily "distribution" of energy and macronutrient intakes. There is a vast amount of research supporting this rationale for CHO intakes in relation to promoting pre-match CHO loading and post-match muscle glycogen resynthesis (Ivy et al., 1988a; Ivy et al., 1988b). Similar to CHO intake, timing and distribution of protein doses may have more of an influential role in modulating muscle protein synthesis when compared with the absolute dose of protein intake *per se*, an effect which is evident on response to both feeding alone (Mamerow et al., 2014) and post exercise feeding (Areta et al., 2013; MacNaughton et al., 2016). Research on the daily distribution of energy and macronutrient intakes has been undertaken in elite youth players from an English soccer team (Naughton et al., 2016), adult elite players of the Dutch league (Bettonviel et al., 2016) and a mixed sex cohort of multisport Dutch athletes (Gillen et al., 2016), all of whom observed a skewed approach to protein feeding across the day.

Information regarding the distribution of energy, CHO and macronutrient intakes would allow practitioners to alter current practices to allow for greater adaptation and performance, specifically around training and matches. In Chapter 6 of this thesis, the daily distribution of energy and macronutrient intakes on both training and match days was quantified. It was observed that players adopt a skewed approach to feeding on training days such that absolute EI, CHO and protein intake are consumed in a hierarchical manner of dinner>lunch>breakfast>snacks. In addition, players tended to under consume CHO on match days in relation to the pre- and post-match meals, especially in recovery from an evening kick-off time. In relation to training days, it is clear that players should distribute their macronutrients more evenly across the day with regular 30-40 g servings of protein at each meal in order to maximise adaptations (Mamerow et al., 2014; Areta et al., 2013; MacNaughton et al., 2016). Recommendations for improvements for soccer players in this regard can be to educate and create awareness around typical protein doses in common foods.

On match day itself, players often cited not wanting to experience the feelings of a “heavy stomach” in the build-up and during the match as their reason behind consuming a lower energy and CHO based pre-match meal. Therefore, different strategies should be adopted in order to meet the 1-4 $g.kg^{-1}$ CHO guidelines in the 1-4 hours prior to matches (Burke et al., 2011). Such strategies should focus around the consumption of medium to high GI CHO in the hours before competition in order to remove the feelings of a “heavy stomach” due to decreased fiber and gluten found in these foods. However, if these foods are provided for the pre match meal, CHO should be provided during the match in order to maintain plasma glucose levels and CHO stores during competition (Burke et al., 1998). In addition to the pre-match meal, the post-match recovery meal requires significant attention in this cohort, especially after an evening kick-off where players are choosing to attempt to go to sleep rather than consume a post-match meal. Players should consume a post-match meal of 1.2 $g.kg^{-1}$ for 4 hours after cessation of exercise in order to maximise muscle glycogen resynthesis (Jentjens & Jeukendrup, 2003). Possible ways to overcome this issue is to provide players with a “recovery pack” after games, such packs should consist of high CHO and high protein.

9.3.2.4. ENERGY AND MACRONUTRIENT INTAKE IN THE GOALKEEPER

The GK in professional soccer often undergoes separate training load and displays significantly less load during matches compared to their outfield teammates (Di Salvo et al., 2008; Bradley et al., 2010). However, the GK is often subject to consuming foods alongside their outfield teammates, foods that are predominantly high in CHO and served on the basis that outfield players are required to have high CHO intakes. Typically, GKs are taller, heavier and have higher levels of body fat than players in other positions in the team (Milsom et al., 2015; Sutton et al., 2009). The latter potentially being down to poor diet choices, which are in line with outfield players’ requirements. Indeed this is a cause for concern as fat mass acts as a dead weight in activities when the body is lifted against gravity (Reilly, 1996). GKs are required to move their bodies in a powerful, explosive and efficient manor in order to be effective in their role within the team. Therefore, it would be highly beneficial to observe a GKs energy and macronutrient intakes across a weekly micro-cycle

In Chapter 7 of this thesis, an elite professional GKs energy and macronutrient intakes across a weekly micro-cycle consisting of two competitive matches was examined. The observed average daily EI of the GK was 3160 kcals across the weekly micro-cycle, however this ranged from 2695 – 3607 kcals. This was reflective in a form of CHO periodisation similar to that observed in outfield players (Anderson et al., 2017; Chapter 6). Although the GK consumed similar protein intakes to his outfield teammates (2.4 $g \cdot kg^{-1}$ vs. 2.6 $g \cdot kg^{-1}$), he consumes considerably higher fat intake (1.9 $g \cdot kg^{-1}$ vs. 1.3 $g \cdot kg^{-1}$) and appeared to self-select a low CHO high fat diet

9.2.2.5. ENERGY AND MACRONUTRIENT INTAKE IN THE INJURED ATHLETE

In recent years, the pressure for a fast return from injury, along with maintained performance upon return has initiated the increase in sports science support of injured athletes. For major injuries in professional soccer, players can often impose upon lengthy periods of rehabilitation, which present major challenges in maintaining lean muscle mass and function. ACL injuries are common and potentially serious injuries in soccer often requiring surgical reconstruction (Brophy et al., 2012). After ACL reconstruction, an athlete's return to play time has been shown to be between 4 and 9 months (Zaffagnini et al., 2014). A time period of this duration requires gradual transition through different phases in order to redevelop a fully functioning, recovered athlete. However, research on training load, EE and EI in professional soccer players undergoing a period of rehabilitation is scarce. One study performed by our group previously (Milsom et al., 2015) provided a case study account of the nutrition, training and rehabilitation program and the subsequent body composition changes at different stages of the rehabilitation. This gives practitioners a better understanding and guide on areas to focus on for improving current practice. Nevertheless, one difficulty expressed by the authors was that typical EE were unknown. In order to provide improved and more accurate nutritional programs over a rehabilitation period, accurate information regarding the EE of players during specific phases is required. Additionally, it is also important to understand the current energy and macronutrient intakes and the distribution, which they are consumed in order to maximise training adaptations during this period (Mamerow et al., 2014; Areta et al., 2013; MacNaughton et al., 2016). Correct practice in this area can provide positive outcomes in regards to the body composition changes over the rehabilitation period enabling a faster, safer and more effective return to play.

In Chapter 8 of this thesis, direct measurements of EE (using the DLW method) were quantified for the first time in an elite English Premier League player undergoing a period of rehabilitation. Additionally, the players daily energy and macronutrient intakes were also quantified across the same 7-day period. In relation to this specific player, our data suggest that he exhibited a significant average energy deficit, has a wide range of energy and macronutrient intakes from day-to-day, has a skewed energy and macronutrient intake across meals. The data from this case study can allow future nutritional and training programs to be implemented allowing for subtle changes around specific meal feeding and overall daily nutritional intake.

9.3.3. CONTEMPORARY TRAINING AND NUTRITIONAL GUILDELINES FOR SOCCER PLAYERS

9.3.3.1. TRAINING GUIDELINES

Through the completion of Chapters 4 and 5, it is clear that during a one-game per week schedule there is significant periodisation within the weekly training load. From a physiological perspective this is essential in order to provide enough recovery from the previous competitive fixture (Nedelec et al., 2015), provide higher volume and intensity training loads early in the micro-cycle in order to provide a physical overload stimulus, with volume decreasing as match day approaches to facilitate decay of the fatigue component (Impellizzeri et al., 2004; Malone et al., 2015; Anderson et al., 2015; Chapter 4). However, it is clear from Chapter 4 of this thesis that match play itself provides the highest physical stimulus during the weekly micro-cycle. Additionally, in Chapter 5 of this thesis it was found that fringe players and non-starters performed less high-intensity and sprint distance than players who were regularly starting fixtures. Therefore, fringe and non-starting players should perform additional high-intensity work when they are not performing in the weekly fixture in order to provide a similar physical stimulus as the starting group (see Table 9.1.). Strategies to provide a similar external output to matches have recently been investigated and have been adopted in the present recommendations in order to provide match like adaptations to ~60 minutes of match play (Lacome et al., 2017). Prior to considering any nutritional strategy, it is essential to identify the physical loading patters experienced across the target training cycle. As an example, a weekly training schedule that has been summerised can be found in Table 9.1 which then provides a framework for a suggested nutritional periodisation strategy to follow.

9.3.3.2. MATCH DAY NUTRITION

Nutrition on match day has a significant impact on physical and technical performance (Williams & Serratosa, 2006). Despite clear nutritional guidelines for match play available in the literature, it appears that the present players studied did not fully adhere to such recommendations. In relation to match performance, increased feeding at the pre-match meal to ~2g.kg^{-1} body mass and increase feeding through breaks in play to ~60 g.h^{-1} is suggested. Such strategies are likely to induce physiological benefits that are facilitative of improved high-intensity intermittent performance by maximising muscle glycogen and liver stores pre-game and maintaining plasma glucose in order to spare muscle and liver glycogen, respectively (Convertino et al., 1996; Coyle, 2004; Coyle, 1992). In addition to the performance benefits of meals, in relation to a two game per week schedule, there is an obvious nutritional requirement to maximise muscle glycogen storage in the 24-48 h after the game (Krsutrup et al., 2006; Bassau et al., 2002). Intakes in the present study would be considered sub-optimal in relation to maximizing rates of post-match muscle glycogen resynthesis (Jentjens & Jeukendrup, 2003). In addition, this seems to be more pronounced when an evening kick off (19:45) occurs with players opting for attempted sleep rather than promoting muscle glycogen resynthesis. Therefore, it is suggested that the current practices can be altered and different approaches should be employed to the feeding strategies employed on match day. An example of CHO intakes on match day along with practical examples can be found in Table 9.2.

9.3.3.3. TRAINING DAY NUTRITION

It is clear from this thesis that training loads are significantly less than that experienced during matches. Therefore, the CHO guidelines on training days are not required to be as high as match day (see Table 9.2.). However, as suggested in Chapter 6, when two competitive matches are played over the weekly micro-cycle there becomes a need to increase CHO intakes in order to maximise muscle glycogen resynthesis and storage between competitive fixtures. Therefore, similar dietary intakes to the Friday and Sunday (for the starters) will be required in the days between fixtures.

In addition to the absolute daily intakes on training days, Chapter 6 of this thesis also observed skewed energy and macronutrient intakes across meals. Providing a balanced approach across to meals to energy and macronutrients, with a particular reference to protein can play an influential role in modulating muscle protein synthesis. Protein intakes were skewed in the hierarchical manner dinner>lunch>breakfast>snacks. The data from this Chapter suggest that improvements can be made at breakfast, morning, afternoon and evening snacks. It is therefore recommended that ~30g of protein should be consumed with each meal displayed in table 9.2. in order to maximise adaptation.

9.3.3.4. CARBOHYDRATE PERIODISATION IN SOCCER

It is important that players are appropriately fueled for training sessions in order to maximise their capabilities to perform technical and cognitive skills (Ali & Williams, 2009; Russell & Kingsley, 2014) and also maintain a high level of physical performance (Harper et al., 2017). Nonetheless, it is likely that players adopt a subconscious "fuel for the work" required approach due to training times, lack of CHO provisions in training sessions and an understanding of CHO loading for matches. From a practical perspective, it is becoming clear that CHO availability should be manipulated in a day-by-day and meal-by-meal manner depending on the upcoming and previous workloads. A practical model for CHO and/ or energy periodisation according to the principle of "fuel for the work required" for a one game per week micro-cycle in professional soccer context is displayed in Table 9.2. In this model, moderate CHO is available prior to training sessions in order to maintain training intensity (Widrick et al., 1993; Yeo et al., 2008; Hulston et al., 2010). During training sessions, no CHO is provided in order to maximise adaptations of a "train low" strategy (Morton et al., 2009). Training sessions during the week were deemed not necessary to provide exogenous CHO for fuel, as muscle glycogen would likely not be fully depleted by the end of the session with regards to the data observed in Chapter 4. Immediately post-training sessions, a high CHO based lunch in order to replenish muscle glycogen stores is suggested, as muscles are more receptive to CHO feeding after exercise has been performed (Ivy et al., 1998). However, careful attention must be paid to training load as each club can potentially have much higher or lower training loads and therefore CHO intakes will have to be adjusted accordingly. Table 9.2. illustrates a practical example of training for the current nutritional framework presented.

Essentially, this model can be adapted for when two competitive games are played in the weekly micro-cycle For example, Saturday-Wednesday-Saturday fixture schedules as often experienced in the English Premier League when teams are competing in major European Competitions alongside the domestic campaign. This can be done following the MD approach as outlined in Table 9.2. For example, Saturday is MD, Sunday is MD+1, Monday is MD+2 and Tuesday is MD-1 and so forth.

Table 9.1. Training guidelines which encompass different aspects of soccer training which would suit the nutritional guidelines set out beneath

	MD+2	MD-4	MD-3	MD-2	MD-1	MD	MD+1
	Monday	**Tuesday – 10:30**	**Wednesday – 10:30**	**Thursday – 10:30**	**Friday – 15:00**	**Saturday**	**Sunday**
Session Type	Off	**Intensive** Small pitch sizes (e.g. 25x20m) Small numbers (e.g. 4v4) Short duration (e.g. 3 minutes) Work: rest - 3:2	**Extensive** Large pitch sizes (e.g. 70x60m) Large numbers (e.g. 11v11) Long duration (e.g. 10 minutes) Work: Rest - 10:1	**Taper** Technical work (e.g. passing exercise) Medium pitch sizes (e.g. 50x40m) Large numbers (e.g. 11v11) Short duration (e.g. 4 minutes) Work: rest - 2:1	**Preparation** Technical work (e.g. rondos 8v2) Small pitch sizes (e.g. 40x30m) Large pitches (walking) Short duration (e.g. 2-3 minutes) Work: rest - 1:1	Game	**S = Indoor Aerobic Recovery Session** **NS = Intensive and extensive work** Medium and small pitch sizes (e.g. 40x40 m and 30x25 m) Large and small numbers (e.g. 8v8 and 4v4) Long and short duration (e.g. 10 and 4 minutes) Work: rest (e.g. 5:1 and 2:1)
GPS Targets		**Duration = 70-80 mins TD = ~5000m HSR = <100m**	**Duration = 80-90 mins TD = 6500m HSR = 250-400m**	**Duration = < 70 mins TD = < 4500m HSR = <100m**	**Duration = <60 mins TD = <3000m HSR = <50m**		**Duration = 70 minutes TD = ~6500m HSR = ~1200m**
Drill 1		Dynamic Warm Up – 10 minutes	Dynamic Warm Up – 10 minutes	Dynamic Warm Up – 10 minutes	Dynamic Warm Up – 10 minutes		Dynamic Warm Up – 10 minutes
Drill 2		Conditioning – 10 minutes	Conditioning – 10 minutes	Technical exercises – 10 minutes	Reaction exercises – 5 minutes		Possession exercise – 10 minutes
Drill 3		Possession exercises (4v4) – 20-25 minutes	Possession exercises (10v10) – 25-30 minutes	Individual specific technical/ tactical – 10 minutes	Rondos – 15 minutes		Game exercise – (8v8) – 20 minutes
Drill 4		Game exercise (4v4) – 25-30 minutes	Game exercise (11v11) – 25-30 minutes	Game exercise (11v11) – 15 minutes	Tactical work – (11v11) – 15-20 minutes		Game exercise – (4v4) – 20 minutes
Drill 5					Game exercise (11v11) – 10 minutes		Aerobic conditioning – 10 minutes
		Lower Limb Strength – 14:00					

TD = Total distance, HSR = High speed running, MD = Match day, S = Starters, NS = Non-starters, GPS = Global positioning systems

Table 9.2. Suggested practical model of the fuel for the work required model to suit an elite professional soccer club. The model is presented for a one-game per week micro-cycle in professional soccer players who are training on the pitch once per day. In this example, the players have five main feeding points and the CHO content of each time-point is colour coded according to a Red, Amber or Green (RAG) rating that represents low, medium and high CHO intake. For guidelines low (<0.75 $g.kg^{-1}$), medium (0.75-1.5 $g.kg^{-1}$) and high (>2 $g.kg^{-1}$) are advised but flexibility is required in relation to player history, training status and specific training goals etc. The model illustrates how certain train-low paradigms can be amalgamated to adjust CHO availability day-by-day and meal-by-meal according to the fuel for the work required model.

	Breakfast	During Training/ Game	Lunch/ Pre Match Meal	Snack/ Post Match	Dinner/ Post Match Recovery Meal
Monday (MD+2)	LOW	NO TRAINING	MEDIUM	LOW	LOW
Tuesday (MD-4)	MEDIUM	LOW – WATER ONLY	HIGH	MEDIUM	LOW
Wednesday (MD-3)	MEDIUM	LOW – WATER ONLY	HIGH	MEDIUM	LOW
Thursday (MD-2)	MEDIUM	LOW – WATER ONLY	HIGH	MEDIUM	MEDIUM
Friday (MD-1)	HIGH	HIGH	HIGH	HIGH	HIGH
Saturday (MD)	HIGH	HIGH	HIGH	HIGH	HIGH
Sunday = S (MD+1)	HIGH	HIGH	HIGH	HIGH	HIGH
Sunday = NS (MD+1)	MEDIUM	LOW – WATER ONLY	HIGH	MEDIUM	MEDIUM

MD = Match day, S = Starters, NS = Non-starters

9.4. GENERAL DISCUSSION

Although this thesis provides valuable information around the typical loading patterns, average daily EE and daily energy and macronutrient intakes of English Premier League soccer players, it must be acknowledged that this is highly observational. The observational findings from this thesis have provided the information to develop a practical nutritional model for elite soccer players. However, experimental research studies discussed below are now required in order to test the theoretical nutritional framework outlined from the results of this thesis.

9.5. RECOMMENDATIONS FOR FUTURE RESEARCH

The data presented in this thesis has largely adopted assessments of training load in order to make inferences on nutritional requirements. However, there is now a definitive need to better understand the direct energy and CHO cost of soccer specific training sessions across the weekly micro-cycle. To this end, a number of suggested areas for future research are presented below:

1. Quantification of muscle glycogen utilization during field based training where muscle biopsies are collected before and after a typical pitch based training session.

2. Quantification of muscle glycogen availability across the weekly micro-cycle where muscle biopsies are obtained on multiple days to examine if players' habitual CHO intakes are sufficient to maintain glycogen availability day-to-day.

3. Examining the effects of undertaking an acute pitch based training session with high or low CHO availability on the molecular regulators of training adaptation, akin to the fuel for the work required principle.

4. Examining the chronic muscle and performance adaptations induced by completing a block of soccer-specific training with high or low CHO availability.

In summary, the work undertaken in this thesis has quantified the typical physical loading patterns of professional soccer players according to fixture schedule, starting status and in special populations such as the goalkeeper and injured player. Additionally, the quantification of energy intake and energy expenditure (using DLW) also provides the first report of energy expenditure in elite Premiership soccer players. When taken together, these data therefore provide a theoretical framework for soccer-specific nutritional guidelines especially in relation to the concept of nutritional (specifically, carbohydrate) periodisation. Further studies are now required to quantify the specific energy and carbohydrate cost of habitual training sessions completed.

CHAPTER 10

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APPENDICES

European College of Sports Scientists, Vienna, Austria, July 2016.

QUANTIFICATION OF NUTRITIONAL INTAKE DURING A CONGESTED FIXTURE PERIOD IN PLAYERS FROM THE ENGLISH PREMIER LEAGUE

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Introduction

Muscle glycogen is the primary energy source during soccer match play (Krustrup *et al.* 2006). In times of fixture congestion (i.e. consecutive matches every 2-3 days), it has therefore been suggested that soccer players consume high daily carbohydrate (CHO) intake (>6 g/kg) in an attempt to promote muscle glycogen re-synthesis and match day physical performance (Anderson et al. 2015). The aim of this study was to therefore quantify daily energy intake and macronutrient composition in English Premier League (EPL) soccer players undergoing a period of fixture congestion.

Methods

Six professional EPL (from one team) soccer players (mean ± SD; age: 27 ± 3 years, body mass: 80.5 ± 8.7 kg, height: 180 ± 7 cm, body fat: 11.9 ± 1.2%, lean body mass, LBM: 65.0 ± 6.7 kg) completed daily food diaries alongside the remote food photographic method (RFPM) over a 7-day period consisting of 2 competitive games (Day 2 and 5) and 5 training sessions (Day 1, 3, 4, 6 and 7). Data were analysed for total daily energy, CHO, protein and fat intake using dietary analysis software (Nutritics Ltd, Ireland).

Results

Energy intake was greater on ($P<0.05$) match days (MD) (3789 ± 577 kcal and 61.1 ± 12.5 kcal/kg LBM) compared with training days (TD) (2948 ± 686 kcal and 45.2 ± 12.2 kcal/kg LBM, respectively). Similarly, CHO intake was also greater ($P<0.05$) on MD (6.4 ± 2.2 g/kg) compared with TD (4.2 ± 1.6 g/kg). In contrast, neither protein (2.7 ± 0.4 g/kg v 2.5 ± 0.7 g/kg) nor fat intake (1.5 ± 0.6 g/kg v 1.2 ± 0.2 g/kg) was different between MD and TD, respectively. CHO intake during matches (35.8 ± 21.5 g/min) was also different ($P<0.05$) from that consumed during training sessions (5.5 ± 10.3 g/min).

Discussion

In accordance with current sports nutrition guidelines (Burke et al. 2011), we conclude elite soccer players consume apparently adequate energy and CHO intake for the typical loads observed on MD versus TD. However, on the basis of a congested fixture period (i.e. 2 days between games), we suggest players should consume higher daily energy and CHO intakes (similar to those reported on MD) on TD between matches so as to promote glycogen re-synthesis in recovery from match play and prepare for the subsequent game.

References

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