



LEEDS  
BECKETT  
UNIVERSITY

---

Citation:

Costello, NB and Deighton, K and Preston, T and Matu, J and Rowe, J and Jones, B (2018) Are professional young rugby league players eating enough? Energy intake, expenditure and balance during a pre-season. *European Journal of Sport Science*. ISSN 1536-7290 DOI: <https://doi.org/10.1080/17461391.2018.1527950>

Link to Leeds Beckett Repository record:

<https://eprints.leedsbeckett.ac.uk/id/eprint/5346/>

Document Version:

Article (Accepted Version)

---

This is an Accepted Manuscript of an article published by Taylor & Francis in *European Journal of Sport Science* on 07 October 2018, available online: <http://www.tandfonline.com/10.1080/17461391.2018.1527950>

The aim of the Leeds Beckett Repository is to provide open access to our research, as required by funder policies and permitted by publishers and copyright law.

The Leeds Beckett repository holds a wide range of publications, each of which has been checked for copyright and the relevant embargo period has been applied by the Research Services team.

We operate on a standard take-down policy. If you are the author or publisher of an output and you would like it removed from the repository, please [contact us](#) and we will investigate on a case-by-case basis.

Each thesis in the repository has been cleared where necessary by the author for third party copyright. If you would like a thesis to be removed from the repository or believe there is an issue with copyright, please contact us on [openaccess@leedsbeckett.ac.uk](mailto:openaccess@leedsbeckett.ac.uk) and we will investigate on a case-by-case basis.

1 **Are professional young rugby league players eating enough?**  
2 **Energy intake, expenditure and balance during a pre-season.**

3  
4 Running Head: 'Energy Balance of Professional Young Rugby League Players during a Pre-  
5 Season'

6  
7 Nessian Costello<sup>1,2,3</sup>, Kevin Deighton<sup>1</sup>, Thomas Preston<sup>4</sup>, Jamie Matu<sup>5</sup>, Joshua Rowe<sup>1</sup>, Ben  
8 Jones<sup>1,2,6,7</sup>

9  
10 1 Leeds Beckett University, Institute for Sport, Physical Activity and Leisure, Leeds, United  
11 Kingdom.

12 2 Leeds Rhinos RLFC, Leeds, United Kingdom

13 3 Leeds United FC, Leeds, United Kingdom

14 4 Stable Isotope Biochemistry Laboratory, Scottish Universities Environmental Research  
15 Centre, Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride, Scotland

16 5 Leeds University, Faculty of Medicine and Health, Leeds, United Kingdom

17 6 Yorkshire Carnegie RUFC, Leeds, United Kingdom

18 7 The Rugby Football League, Leeds, United Kingdom

19  
20  
21 Corresponding Author

22 Nessian Costello

23 Room G03, Macaulay Hall,

24 Institute for Sport, Physical Activity and Leisure,

25 Centre for Human Performance,

26 Headingley Campus, Leeds Beckett University

27 W. Yorkshire, LS6 3QS

28 Phone: (0044) 7837367874

29 Email: [N.Costello@leedsbeckett.ac.uk](mailto:N.Costello@leedsbeckett.ac.uk)

30  
31 Author Information

32 Dr Kevin Deighton: [K.Deighton@leedsbeckett.ac.uk](mailto:K.Deighton@leedsbeckett.ac.uk)

33 Prof. Thomas Preston: [Tom.Preston@glasgow.ac.uk](mailto:Tom.Preston@glasgow.ac.uk)

34 Dr. Jamie Matu: [J.Matu@leedsbeckett.ac.uk](mailto:J.Matu@leedsbeckett.ac.uk)

35 Joshua Rowe: [Joshua.Rowe@leedsbeckett.ac.uk](mailto:Joshua.Rowe@leedsbeckett.ac.uk)

36 Prof. Ben Jones: [B.Jones@leedsbeckett.ac.uk](mailto:B.Jones@leedsbeckett.ac.uk)

37  
38  
39 Word Count: 3272

40 Abstract Word Count: 249

## Abstract

41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64

Due to the unique energetic demands of professional young collision sport athletes, accurate assessment of energy balance is required. Consequently, this is the first study to simultaneously investigate the energy intake, expenditure and balance of professional young rugby league players across a pre-season period.

The total energy expenditure of six professional young male rugby league players was measured via doubly labelled water over a fourteen-day assessment period. Resting metabolic rate was measured and physical activity level calculated. Dietary intake was reported via Snap-N-Send over a non-consecutive ten-day assessment period, alongside changes in fasted body mass and hydration status. Accordingly, energy balance was inferred.

The mean (standard deviation) difference between total energy intake (16.73 (1.32) MJ·day<sup>-1</sup>) and total energy expenditure (18.36 (3.05) MJ·day<sup>-1</sup>) measured over the non-consecutive ten-day period was *unclear* (-1.63 (1.73) MJ·day<sup>-1</sup>; ES = 0.91 ±1.28; *p* = 0.221). This corresponded in a most likely *trivial* decrease in body mass (-0.65 (0.78) kg; ES = 0.04 ±0.03; *p* = 0.097). Resting metabolic rate and physical activity level across the fourteen-day pre-season period was 11.20 (2.16) MJ·day<sup>-1</sup> and 1.7 (0.2), respectively.

For the first time, this study utilises gold standard assessment techniques to elucidate the distinctly large energy expenditures of professional young rugby league players across a pre-season period, emphasising a requirement for equally large energy intakes to achieve targeted body mass and composition adaptations. Accordingly, it is imperative that practitioners regularly assess the energy balance of professional young collision-sport athletes to ensure their unique energetic requirements are achieved.

**Key words:** Dietary intake, Energy expenditure, Doubly labelled water, Energy balance, Rugby

65 **Highlights:**

66 Professional young rugby league players displayed distinctly large energetic demands during  
67 a pre-season period, emphasising a requirement for equally large energy intakes to achieve  
68 targeted body mass and composition goals.

69 Despite consuming large average energy intakes, professional young rugby league players  
70 were still susceptible to an energy deficit and losing body mass, potentially negatively  
71 affecting targeted training adaptations across key developmental periods i.e. pre-season  
72 within a young athlete cohort.

73 Accordingly, it is imperative that practitioners and coaches operating within professional  
74 collision-based sports regularly assess and behaviourally support achievement of energy  
75 balance across pre-season periods to maximise the physical and anthropometric development  
76 of professional young collision-sport athletes.

77

78

79

## 80 **Introduction**

81 Professional young rugby league (RL) players require a sufficient energy intake and a  
82 high-quality diet to support optimal training adaptation and development across pre-season  
83 periods (Logue et al., 2018; Thomas, Erdman, & Burke, 2016). Rugby league is an  
84 intermittent team sport characterised by repeated collisions and high-intensity running efforts  
85 (Weaving et al., 2018), which results in considerable exercise- and collision-induced muscle  
86 damage (Naughton, Miller, & Slater, 2017), prolonged muscle soreness (Fletcher et al., 2016)  
87 and increased energy expenditure (Costello et al., 2018b) following training or match-play. A  
88 sufficient energy and macronutrient intake is required to fuel such demands (Logue et al.,  
89 2018; Thomas et al., 2016), while promoting targeted increases in fat-free and overall body  
90 mass (BM) required within professional collision sport cohorts (Brazier et al., 2018; Till,  
91 Scantlebury, & Jones, 2017). This is particularly true of elite young collision sport athletes,  
92 whose already distinct maturation (COMA, 1991) and home-based demands (e.g. academic  
93 and social stresses) (Desbrow et al., 2014) are combined with increased training loads to  
94 drive adaption across periods of pivotal physical development i.e pre-season (Brazier et al.,  
95 2018; Till, Scantlebury, & Jones, 2017). Evidently, excellent nutritional support is required  
96 across such periods to safeguard player well-being and health, while promoting maximal  
97 development.

98 Published literature investigating the dietary intakes of professional young RL players  
99 is limited (Smith, Jones, Sutton, King, & Duckworth, 2016), which makes accurate  
100 evaluation of current nutritional practise difficult. To date, four published studies have  
101 investigated the dietary intakes of professional RL players (Lundy, O'Connor, Pelly, &  
102 Caterson, 2006; MacKenzie, Slater, King, & Byrne, 2015; Smith et al., 2016; Tooley, Bitcon,  
103 Briggs, West, & Russell, 2015), however only one has specifically examined the energy and  
104 macronutrient intakes of professional young RL players during a pre-season period (Smith et

105 al., 2016). Although informative, such research is confounded by the use of traditional dietary  
106 assessment tools (four-day food diary), which have not been robustly validated for use within  
107 athletic populations (Capling et al., 2017). Subsequently, traditional dietary assessment  
108 methods typically report substantial errors of both validity and reliability (Dhurandhar et al.,  
109 2014). For example, a combined food diary and 24-hour dietary recall interview resulted in  
110 physiologically implausible energy intakes within a professional senior RL population (2030  
111 kcal·day<sup>-1</sup> under-reporting error; Morehen et al., 2016), while reporting unacceptable  
112 measurement error within a professional young RL population (690 kcal·day<sup>-1</sup> under-  
113 reporting error; Costello et al., 2017). Clearly, improved evaluation of dietary intakes  
114 utilising more accurate dietary assessment tools is warranted within professional young  
115 collision sports.

116 Current literature investigating the total energy expenditure (TEE) of professional  
117 young RL players is limited to one in-season assessment (Smith et al., 2018), which makes  
118 formulating precise, individualised dietary strategies during a pre-season difficult. To date,  
119 only four published studies have investigated the TEE of professional rugby players (Bradley  
120 et al., 2015; Morehen et al., 2016; Smith et al., 2018; Tooley et al., 2015). Such research is  
121 confounded by the use of invalid assessment tools, although the literature gold standard  
122 doubly labelled water (DLW)(Westerterp, 2017) has been utilised to accurately determine the  
123 TEE of professional senior (Morehen et al., 2016) and young RL players (Smith et al., 2018)  
124 during the season. Despite this, no study to date has specifically investigated the energetic  
125 demands of professional young RL players across a physically challenging pre-season period,  
126 where maximal physical adaptations are targeted (Brazier et al., 2018; Till, Scantlebury, &  
127 Jones, 2017). Subsequently, due to the unique energetic demands of adolescent athletes  
128 (COMA, 1991; Desbrow et al., 2014) and collision-based sports (Costello et al., 2018b),

129 accurate assessment of energy balance is required across pre-season periods within a  
130 professional young RL population.

131 Therefore, this study utilised gold standard assessment techniques to investigate the  
132 energy intake, expenditure and balance of professional young RL players for the first time  
133 across a fourteen-day pre-season assessment period.

134

## 135 **Methods**

### 136 **Participants**

137 Six healthy, professional young (age range 16 to 18 years) male RL players (mean  
138 (SD) age; 17 (1) years, height; 178.2 (9.4) cm, BM; 87.4 (14.7) kg) were recruited.

139 Participants were chosen from a range of playing positions including Loose Forward, Prop  
140 Forward (x2), Half Back, Hooker and Wing. All participants provided written informed  
141 consent, prior to volunteering. Ethics approval was granted by the Carnegie Faculty Research  
142 Ethics Committee (Leeds Beckett University, UK).

### 143 **Design**

144 Study data were collected over a fourteen-day assessment period, during the sixth and  
145 seventh week of a pre-season period. The period included ten resistance-training sessions, ten  
146 field sessions and four rest days (Table 1). Total energy expenditure was measured via DLW  
147 across the entire fourteen-day period, whereas dietary intake was reported via 'Snap-N-  
148 Send'(Costello et al., 2017; Costello et al., 2017b) across a shorter non-consecutive ten-day.  
149 A shorter dietary assessment period was specifically chosen to ensure high behavioural  
150 compliance to accurate dietary reporting amongst participants (Monday-Friday) (Costello et  
151 al., 2017; Costello et al., 2017b). Therefore, in order to determine energy balance, TEE was  
152 also calculated from DLW data collected during the corresponding non-consecutive ten-day  
153 dietary assessment period. The RMR of participants was measured one day prior to the start

154 of each training week (Sunday) and averaged to obtain a mean value. This allowed for  
155 physical activity level (PAL) to be calculated. Changes in fasted BM and hydration status  
156 were assessed on Monday and Saturday of both assessment weeks, providing an objective  
157 assessment of energy balance. The training and home-based loads of participants were  
158 recorded via sessional ratings of perceived exertion (sRPE) (Foster et al., 2001), micro-  
159 technology units and SenseWear Armbands (SWA), respectively.

160

161 **INSERT TABLE 1 HERE**

162

### 163 **Dietary Intake**

164 Energy and macronutrient intakes were analysed via ‘Snap-N-Send’ across a non-  
165 consecutive ten-day assessment period. The combined non-consecutive period included  
166 Monday-Friday of both assessment weeks. Two non-consecutive five-day dietary assessment  
167 periods were specifically chosen so that participants received a break from dietary reporting  
168 over the weekend, enhancing the quality of analysis likely to be obtained (Costello et al.,  
169 2017b). Importantly, a shorter seven-day assessment period is considered accurate  
170 representation of habitual energy and macronutrient intakes (Braakhuis, Meredith, Cox,  
171 Hopkins, & Burke, 2003). Moreover, ‘Snap-N-Send’ is a dietary assessment tool specifically  
172 designed and validated for use within an elite adolescent athlete cohort, reporting enhanced  
173 validity and reliability over traditional dietary assessment tools (Costello et al., 2017) via  
174 novel addressment of both methodological and behavioural dietary assessment error (Costello  
175 et al., 2017b).

176 Prior to the study period, participants attended a preliminary workshop where they  
177 were verbally, visually and kinaesthetically taught how to use ‘Snap-N-Send’. The method  
178 was explained in detail and demonstrated across a number of potentially difficult recording



179 scenarios ('if-then' situations, i.e. periods with limited smartphone or Wi-Fi access). All  
180 participants had to individually demonstrate recording competence before the workshop was  
181 completed. Population-specific behaviour change techniques (BCTs), designed and  
182 implemented via the Behaviour Change Wheel (Michie et al., 2014), were applied across the  
183 preliminary workshop and assessment period to behaviourally adhere participants to accurate  
184 real-time ecological momentary assessment. For detailed explanation of 'Snap-N-Send' or  
185 the BCTs employed throughout the preliminary workshop or assessment period please see  
186 (Costello et al., 2017).

187 Dietary intakes were analysed by a SENr accredited nutritionist with applied  
188 experience within the investigated population. When required, portions of food were matched  
189 to pictures provided via 'Snap-N-Send' before being entered for analysis. Energy and  
190 macronutrient intakes were determined from Nutritics dietary analysis software (Nutritics  
191 3.06, Ireland), with items not available on the database manually entered from label  
192 packaging.

193

#### 194 **Total Energy Expenditure measured by Doubly Labelled Water**

##### 195 *DLW Stable Isotope Doses*

196 Two bolus doses consisting of deuterium ( $^2\text{H}$ ) and oxygen ( $^{18}\text{O}$ ) stable isotopes were  
197 prepared for each participant, as has previously been described (Costello et al., 2018b). A  
198 spilt dose protocol was chosen to ensure tracer enrichment in body water remained above the  
199 minimum recommendation throughout the study (IAEA 2009). Doses were calculated  
200 relative to the largest BM of any participant (Schoeller et al., 1980). This included  $^2\text{H}_2\text{O}$  (99  
201 atom %) and  $\text{H}_2^{18}\text{O}$  (10 atom %) based on  $0.14 \text{ g}\cdot\text{kg}^{-1}$  and  $0.90 \text{ g}\cdot\text{kg}^{-1}$  of BM, respectively.

202 *DLW Administration, Urine Collections and IRMS Analyses of Urine Samples*

203 Each dose was provided on Sunday, one day prior to the start of each training week.  
204 Dose administrations occurred after a morning RMR assessment. A baseline urine sample  
205 was provided before oral consumption of a single bolus of DLW ( $^2\text{H}_2^{18}\text{O}$ ), made under close  
206 supervision. To ensure consumption of the whole bolus, the dose bottles were washed twice  
207 with additional water that participants also consumed. Baseline enrichment was determined  
208 from a later urine sample provided by participants at 22:00, allowing for total body water  
209 (TBW) equilibrium. This protocol was repeated exactly for the second dose seven days later.

210 Participants provided daily urine samples at 22:00 across the entire fourteen-day data  
211 collection period. The final urine sample was collected at 06:00 on Monday morning, after  
212 completion of the second training week. Samples were collected directly into two date, time  
213 and participant ID registered 5 mL cryovials and filtered in compliance with the Human  
214 Tissue Act. Analysis of urine samples for  $^2\text{H}$  and  $^{18}\text{O}$  abundance was performed following  
215 gas exchange using a HYDRA 20-22 IRMS (SerCon, Crewe UK), as has previously been  
216 described (Costello et al., 2018b). All data were imported into a Microsoft Excel template for  
217 the calculation of TBW, TEE and quality control parameters.

218

219 *Total Body Water and Total Energy Expenditure Calculations*

220 Participant TBW and TEE were calculated specifically for the fourteen-day  
221 assessment period and non-consecutive ten-day dietary assessment period, so that energy  
222 balance could be investigated. Participant TBW was calculated from stable isotope dilution  
223 spaces, based on the intercept of the elimination plot of deuterium. Whereas, TEE was  
224 determined from the stable isotope elimination rate constants and “pool space” (IAEA 2009).  
225 Specific TEE values were then calculated (Goran, Poehlman, & Danforth, 1994). The  
226 Pearson product moment correlation of the tracer elimination plots was greater than 0.99 in  
227 all cases. A respiratory quotient of 0.85 was assumed (Schoeller & van Santen, 1982).

228

229 **Resting Metabolic Rate**

230 Participants underwent an overnight fast and fifteen-minute enforced rest period  
231 before the beginning of a fifteen-minute assessment. The assessment occurred within a mildly  
232 lit and temperate room (21–23 °C) with participants lying quietly in a supine position  
233 (Compher et al. [2006](#)). Expired gas was analysed using an online gas analyser (Metalyzer  
234 3BR3, Cortex, Leipzig, Germany). The gas analyser was calibrated as per the manufacturer's  
235 guidelines using two known concentrations of each gas (ambient and 15% O<sub>2</sub> and ambient  
236 and 5% CO<sub>2</sub>), daily barometric pressure and a 3-L volume syringe. Participants wore a  
237 facemask connected to a gas analyser for online breath-by-breath analysis. Data were  
238 subsequently averaged every 30 s to remove artefacts and exported to Microsoft Excel (2016,  
239 Seattle, USA), providing an accurate assessment of RMR with a coefficient of variation <10  
240 % (Compher et al., 2006). The respiratory exchange ratio was determined from  $\dot{V}O_2$  and  
241  $\dot{V}CO_2$  measurements (Frayn, 1983). Energy expenditure was estimated from substrate  
242 oxidation rates and expressed per 24 hours, using an energy value for carbohydrate and fat of  
243 3.75 kcal and 9 kcal, respectively (Southgate & Durnin, 1970).

244

245 **Body Mass**

246 To determine change in fasted BM across the non-consecutive ten-day energy balance  
247 assessment period, participants were weighed to the nearest 0.1 kg on Monday and Saturday  
248 of both assessment weeks and change scores were combined. Body mass assessments  
249 occurred after an overnight fast, wearing shorts only, after urination (SECA, Birmingham,  
250 UK). Hydration status was assessed prior to each BM weigh-in, so that observed changes in  
251 BM could be attributed to energy balance rather than fluctuations in hydration status.  
252 Specifically, the second void of the day was collected and analysed for osmolality through

253 freezing point depression (Gonotec, Berlin, Germany). Samples were analysed in triplicate  
254 for each participant and averaged to provide a final osmolality score.

255

### 256 **Training and Home-Based Loads**

257 Training and home-based loads are reported in the supplementary materials. Internal  
258 and external training loads were assessed across all training sessions via sRPE (Foster et al.,  
259 2001) and micro-technological units (Optimeye S5, Catapult Innovations, Melbourne,  
260 Australia; version 5.1.7, 15 (3); horizontal dilution of precision 0.8 (0.6)), respectively.  
261 Microtechnology units were turned on fifteen minutes prior to any session in a clear outdoor  
262 space to achieve a satisfactory satellite lock. Home-based loads were assessed outside of  
263 every training session via SWA (SenseWear Professional version 6.1; BodyMedia, USA), as  
264 has previously been described (Costello et al., 2018b).

265

### 266 **Statistical Analyses**

267 Raw data are presented as mean  $\pm$  standard deviation (SD). Paired t-tests and  
268 magnitude-based inferences (MBI) were used to assess for differences in energy intake and  
269 TEE across the non-consecutive ten-day assessment period, alongside fasted BM and  
270 hydration status. Magnitude-based inferences were included to promote direct interpretation  
271 of observed changes and whether observed changes were meaningful (Hopkins, Marshall,  
272 Batterham, & Hanin, 2009). Paired t-tests and MBI analyses were run in R Studio (v 1.414).

273 For null-hypothesis significance testing, statistical significance was assumed at 5%  
274 ( $P < 0.05$ ). For MBI, the threshold for a change to be considered practically important (the  
275 smallest worthwhile change) was set at  $0.2 \times$  between subject SD, based on Cohen's  $d$  effect  
276 size (ES) principle (Hopkins et al., 2009). Thresholds for ES were set as;  $<0.2$  *trivial*;  $0.2-0.6$   
277 *small*;  $0.6-1.2$  *moderate*;  $1.2-2.0$  *large* (Hopkins et al., 2009). The probability that the

278 magnitude of change was greater than the practically important threshold (0.2 x between  
279 subject SD) was rated as <0.5%, *almost certainly not*; 0.5-4.9%, *very unlikely*; 5-24.9%,  
280 *unlikely*; 25-74.9%, *possibly*; 75-94.9%, *likely*; 95-99.5%, *very likely*; >99.5%, *almost*  
281 *certainly* (Hopkins et al., 2009). The magnitude of change was described as *unclear* when the  
282 90% CI crossed both the upper and lower boundaries of the practically important threshold  
283 (ES  $\pm$ 0.2).

284

## 285 **Results**

### 286 **Dietary Intake**

287 Mean energy intake across the non-consecutive ten-day assessment period was 16.73  
288 (2.40) MJ·day<sup>-1</sup>. Absolute carbohydrate, protein, fat and alcohol intakes were 445 (64) g·day<sup>-1</sup>;  
289 224 (48) g·day<sup>-1</sup>; 149 (25) g·day<sup>-1</sup> and 1.5 (3.7) g·day<sup>-1</sup>, respectively. When expressed relative  
290 to BM, players consumed 5.2 (1.2) g·kg<sup>-1</sup>·day<sup>-1</sup> of carbohydrate, 2.6 (0.8) g·kg<sup>-1</sup>·day<sup>-1</sup> of  
291 protein and 1.8 (0.3) g·kg<sup>-1</sup>·day<sup>-1</sup> of fat.

292

### 293 **Energy Expenditure**

294 Individual values for RMR, TEE and PAL are reported in Table 2. The mean RMR,  
295 TEE and PAL across the fourteen-day assessment pre-season period was 11.20 (2.16) MJ·day<sup>-1</sup>,  
296 18.36 (3.05) MJ·day<sup>-1</sup> and 1.6 (0.2), respectively.

297

298 **INSERT TABLE 2 HERE**

299

### 300 **Energy Balance**

301 Individual values for energy intake, expenditure, balance and fasted BM change  
302 across the non-consecutive ten-day dietary assessment period are reported in Table 3. The  
303 mean difference between energy intake (16.73 (1.32) MJ·day<sup>-1</sup>) and TEE (18.36 (3.05)  
304 MJ·day<sup>-1</sup>) was *unclear* (-1.63 (1.73) MJ·day<sup>-1</sup>; ES = -0.56 ±0.83; *p* = 0.233). The mean  
305 observed BM change was a *most likely* trivial decrease (-0.65 (0.78) kg; ES = -0.03 ±0.02; *p*  
306 = 0.076). Directional changes in BM were consistent with inferred energy balance values in  
307 five out of the six participants (i.e., those with a positive energy balance gained weight and  
308 those with a negative energy balance lost weight). There was a *possibly* trivial decrease in  
309 urine osmolality before BM weigh-ins (0.027 (0.066) mOsmol·kg<sup>-1</sup>; ES = -0.3 ±0.29; *p* =  
310 0.367).

311

312

**INSERT TABLE 3 HERE**

313

## 314 **Discussion**

315 This is the first study to simultaneously investigate the energy intake, expenditure and  
316 balance of professional young RL players across a pre-season period. Gold standard  
317 assessment techniques elucidated the distinctly large expenditures of professional young RL  
318 players across a pre-season, emphasising a requirement for equally large energy intakes to  
319 achieve targeted physical and anthropometric developments. Despite consuming large  
320 average dietary intakes, players were in a self-reported negative energy balance that  
321 corresponded in a mean reduction in fasted BM. Accordingly, it is imperative that  
322 professional young RL players and collision-sport athletes consume a sufficient energy intake  
323 to support optimal training adaption across physically demanding pre-season periods, where  
324 optimal development is targeted. Ultimately, practitioners and coaches are encouraged to

325 regularly assess and behaviourally support desired manipulation of energy balance within  
326 professional young collision sport cohorts to maximise player development across pivotal  
327 pre-season periods.

328         We present novel measured RMR and DLW assessed TEE for professional young RL  
329 players during a pre-season period, which further evidences the distinctly large energy  
330 expenditures of professional RL players and collision-sport athletes. Average TEEs reported  
331 in this study are 819 kcal·day<sup>-1</sup> higher than in-season values reported for professional senior  
332 soccer players via DLW, despite soccer players competing in two competitive matches across  
333 the data collection period (Anderson et al., 2017). On the contrary, reported expenditures are  
334 similar to values stated in-season for professional young rugby players (Smith et al., 2018)  
335 and elite young basketball players (Silva et al., 2013), despite the investigated cohort not  
336 competing in match play across pre-season. Interestingly, such large TEEs are probably a  
337 result of the distinct RMR measured in this study, which are 789 kcal higher than those  
338 reported for professional senior RL players in-season (Morehen et al., 2006). Such large  
339 RMR are possibly a consequence of the substantial muscle damage sustained during high pre-  
340 season training loads prescribed to drive desired player development (Costello et al., 2018b;  
341 Naughton et al., 2017). Collectively, RMR from this study and TEEs previously reported for  
342 both professional young and senior rugby players (Morehen et al., 2016; Smith et al., 2018)  
343 evidence the unique energetic demands of professional collision sport athletes across the  
344 season. Such large and individually varied TEE appear to exceed the kinematic demands of  
345 similar, non-collision based team sports (Anderson et al., 2017), likely influenced by the  
346 large fat-free and overall BM of collision-sport athletes (Till, Scantlebury, & Jones, 2017).

347         Professional young RL players have distinctly large TEEs, therefore require equally  
348 large energy intakes to achieve energy balance and targeted adaptations across challenging  
349 developmental periods. Due to the strenuous physical demands of professional RL and

350 collision-based sports, it is imperative that young players utilise developmental periods (i.e.  
351 pre-season) to increase fat-free and overall BM to maximise their career progression (Brazier  
352 et al., 2018; Till, Scantlebury, & Jones, 2017). To drive desired adaptation, players require a  
353 habitual positive energy balance and high-quality diet (Logue et al., 2018; Thomas et al.,  
354 2016). In this study professional young RL players displayed distinctly large expenditures as  
355 high as 5708 kcal·day<sup>-1</sup>, emphasising a requirement for equally large energy intakes to  
356 achieve the required daily energy surplus needed to increase fat-free mass alongside BM  
357 (Longland, Oikawa, Mitchell, Devries, & Phillips, 2016). Accordingly, it imperative that  
358 practitioners and coaches are aware of the unique energetic demands placed upon  
359 professional young, collision-sport athletes during intensified training periods such as pre-  
360 season.

361         Despite consuming large energy intakes, professional young collision sport athletes  
362 might fail to consistently achieve energy balance across demanding pre-season periods,  
363 potentially affecting targeted physical and anthropometric developments. In this study  
364 professional young RL players consumed a large average energy intake of ~4000 kcal·day<sup>-1</sup>,  
365 634 kcal·day<sup>-1</sup> higher than intakes previously reported for professional young rugby players  
366 during a pre-season (Smith et al., 2016) and ~653 kcal·day<sup>-1</sup> greater than values reported for  
367 professional senior RL players in-season (Morehen et al., 2016). In spite of such intakes,  
368 players still reported consuming 389 kcal·day<sup>-1</sup> less on average than they expended, resulting  
369 in an undesirable reduction in fasted BM. Although a negative energy balance combined with  
370 a high protein diet can result in desirable body composition changes (i.e. decreased fat  
371 mass)(Longland et al., 2016), consistent energy deficits have been shown to result in low  
372 energy availability and a myriad of health defects that greatly ‘*out-weigh*’ benefits in a young  
373 athlete population (Logue et al., 2018). Consequently, professional young collision-sport  
374 athletes are encouraged to account for the energetic ‘*impact*’ of collisions, by (re)fuelling



375 appropriately for the “muscle damage caused” alongside the kinematic “work required”  
376 (Costello et al., 2018b). Whereas, practitioners and coaches operating within professional  
377 collision-based sports are encouraged to objectively assess the energy balance of professional  
378 young RL players via daily fasted BM weigh-ins, supporting desired manipulation of energy  
379 intake via comprehensive, systematic, and theoretical behaviour change science (Costello et  
380 al., 2018).

381         Beyond energetic demands, players seemed to consume appropriate macronutrient  
382 intakes for optimal training, adaptation and recovery (Thomas et al., 2016), most likely an  
383 inevitable consequence of such large overall dietary intakes. In this study, player  
384 carbohydrate consumption was comparative to values reported for professional young and  
385 senior rugby players across pre- ( $4.7 \text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ )(Smith et al., 2016) and in-season periods  
386 ( $4.9\text{-}6.0 \text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ )(Lundy et al., 2006; Tooley et al., 2015). Interestingly, intakes aligned  
387 with current carbohydrate recommendations for moderately trained athletes ( $5\text{-}7 \text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ )  
388 <sup>1</sup>(Desbrow et al., 2014) and more specifically with values advised prior to competitive RL  
389 match-play ( $6 \text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ )(Bradley et al., 2017). Likewise, protein intakes seemed  
390 appropriate within a young resistance trained population, subject to substantial exercise- and  
391 collision-induced muscle damage (Naughton et al., 2017), struggling to consistently attain  
392 energy balance (Costello et al., 2018). Therefore, due to the large dietary intakes reported it  
393 seems likely that players will inevitably consume a sufficient macronutrient profile, further  
394 evidencing a requirement for practitioners to prioritise a sufficient energy intake within  
395 professional collision-based sports.

396         Future research should seek to progress study findings by investigating the energy  
397 balance of professional young RL players during the season, while also examining intakes  
398 within other professional young and senior collision-sport cohorts (i.e. American football,  
399 Australian rules football, rugby union, rugby sevens and Gaelic football). Such research

400 warrants dietary assessment over longer periods inclusive of a weekend, while also  
401 determining participant maturity status due to potential effects on expenditure (COMA,  
402 1991). Future research should also confirm the reliability of dietary outputs via secondary  
403 analysis and prioritise a larger population size (Hopkins et al., 2009); although, the value of a  
404 low powered study that is otherwise well-designed and executed cannot be understated,  
405 especially within future meta-analyses or systematic reviews. For example, this study is  
406 strengthened throughout by the use of previously validated (Costello et al., 2017; Costello et  
407 al., 2017b) assessment methods or gold standard assessment techniques (Compher,  
408 Frankenfield, Keim, & Roth-Yousey, 2006), reducing measurement error within constructs of  
409 energy balance notorious for poor assessment validity and reliability (Dhurandhar et al.,  
410 2014). Ultimately, this increases confidence in study findings and inferred practical  
411 applications.

412         To conclude, this study provides novel insights into the energy intake, expenditure  
413 and balance of professional young RL players during a pre-season period. Despite consuming  
414 large average energy intakes, players reported a daily energy deficit that resulted in an  
415 undesirable loss in BM. Accordingly, practitioners operating within professional collision-  
416 based sports need to be aware of the distinct TEE of professional young collision sport  
417 athletes, ensuring a consistently sufficient energy intake to meet their unique energetic  
418 demands. This is of particular importance within youth athlete cohorts across pivotal  
419 developmental periods (i.e. pre-season). In practise, collision-sport athletes are encouraged to  
420 account for the energetic '*impact*' of collisions, by (re)fuelling appropriately for the "muscle  
421 damage caused" alongside the kinematic "work required". Whereas, practitioners and  
422 coaches are encouraged to regularly assess the energy balance of professional young RL  
423 players via daily fasted BM weigh-ins, supporting desired manipulation of energy intake via  
424 comprehensive, systematic, and theoretical behaviour change science.

## References

- Anderson, L., Orme, P., Naughton, R. J., Close, G. L., Milsom, J., Rydings, D., . . . Morton, J. P. (2017). Energy Intake and Expenditure of Professional Soccer Players of the English Premier League: Evidence of Carbohydrate Periodization. *International Journal of Sport Nutrition and Exercise Metabolism*, 0(0), 1-25. doi: 10.1123/ijsnem.2016-0259
- Braakhuis, A. J., Meredith, K., Cox, G. R., Hopkins, W. G., & Burke, L. M. (2003). Variability in estimation of self-reported dietary intake data from elite athletes resulting from coding by different sports dietitians. *Int J Sport Nutr Exerc Metab*, 13(2), 152-165
- Bradley, W. J., Cavanagh, B., Douglas, W., Donovan, T. F., Twist, C., Morton, J. P., & Close, G. L. (2015). Energy intake and expenditure assessed 'in-season' in an elite European rugby union squad. *Eur J Sport Sci*, 15(6), 469-479. doi: 10.1080/17461391.2015.1042528
- Bradley, W. J., Hannon, M. P., Benford, V., Morehen, J. C., Twist, C., Shepherd, S., . . . Close, G. L. (2017). Metabolic demands and replenishment of muscle glycogen after a rugby league match simulation protocol. *J Sci Med Sport*, 20(9), 878-883. doi: 10.1016/j.jsams.2017.02.005
- Anderson, L., Orme, P., Naughton, R. J., Close, G. L., Milsom, J., Rydings, D., . . . Morton, J. P. (2017). Energy Intake and Expenditure of Professional Soccer Players of the English Premier League: Evidence of Carbohydrate Periodization. *International Journal of Sport Nutrition and Exercise Metabolism*, 0(0), 1-25. doi: 10.1123/ijsnem.2016-0259
- Braakhuis, A. J., Meredith, K., Cox, G. R., Hopkins, W. G., & Burke, L. M. (2003). Variability in estimation of self-reported dietary intake data from elite athletes resulting from coding by different sports dietitians. *Int J Sport Nutr Exerc Metab*, 13(2), 152-165
- Bradley, W. J., Cavanagh, B., Douglas, W., Donovan, T. F., Twist, C., Morton, J. P., & Close, G. L. (2015). Energy intake and expenditure assessed 'in-season' in an elite European rugby union squad. *Eur J Sport Sci*, 15(6), 469-479. doi: 10.1080/17461391.2015.1042528
- Bradley, W. J., Hannon, M. P., Benford, V., Morehen, J. C., Twist, C., Shepherd, S., . . . Close, G. L. (2017). Metabolic demands and replenishment of muscle glycogen after a rugby league match simulation protocol. *J Sci Med Sport*, 20(9), 878-883. doi: 10.1016/j.jsams.2017.02.005
- Brazier, J., Antrobus, M., Stebbings, G., Day, S., Callus, P., Erskine, R., . . . Williams, A. (2018). *The Anthropometric and Physiological Characteristics of Elite Male Rugby Athletes*.
- COMA (1991). Dietary reference values for food energy and nutrients for the United Kingdom. Committee on Medical Aspects of Food Policy, Stationery Office, London
- Compher, C., Frankenfield, D., Keim, N., & Roth-Yousey, L. (2006). Best practice methods to apply to measurement of resting metabolic rate in adults: a systematic review. *J Am Diet Assoc*, 106(6), 881-903. doi: 10.1016/j.jada.2006.02.009
- Costello, N., Deighton, K., Dyson, J., McKenna, J., & Jones, B. (2017). Snap-N-Send: A valid and reliable method for assessing the energy intake of elite adolescent athletes. *Eur J Sport Sci*, 17(8), 1044-1055. doi: 10.1080/17461391.2017.1337815
- Costello, N., McKenna, J., Sutton, L., Deighton, K., & Jones, B. (2018). Using Contemporary Behavior Change Science to Design and Implement an Effective Nutritional Intervention Within Professional Rugby League. *Int J Sport Nutr Exerc Metab*, 1-5. doi: 10.1123/ijsnem.2017-0298
- Costello, N., Deighton, K., Preston, T., Matu, J., Rowe, J., Sawczuk, T., . . . Jones, B. (2018)b. Collision activity during training increases total energy expenditure measured via doubly labelled water. *Eur J Appl Physiol*. doi: 10.1007/s00421-018-3846-7
- Costello, N., McKenna, J., Deighton, K., & Jones, B. (2017)b. Commentary: Snap-N-Send: A Valid and Reliable Method for Assessing the Energy Intake of Elite Adolescent Athletes. *Frontiers in Nutrition*, 4(47). doi: 10.3389/fnut.2017.00047
- Davidsson, L. (2009). *Assessment of Body Composition and Total Energy Expenditure in Humans Using Stable Isotope Techniques*: International Atomic Energy Agency.

- Desbrow, B., McCormack, J., Burke, L. M., Cox, G. R., Fallon, K., Hislop, M., . . . Leveritt, M. (2014). Sports Dietitians Australia position statement: sports nutrition for the adolescent athlete. *Int J Sport Nutr Exerc Metab*, 24(5), 570-584. doi: 10.1123/ijsnem.2014-0031
- Dhurandhar, N. V., Schoeller, D., Brown, A. W., Heymsfield, S. B., Thomas, D., Sørensen, T. I. A., . . . the Energy Balance Measurement Working, G. (2014). Energy balance measurement: when something is not better than nothing. *International Journal Of Obesity*, 39, 1109. doi: 10.1038/ijo.2014.199
- Fletcher, B. D., Twist, C., Haigh, J. D., Brewer, C., Morton, J. P., & Close, G. L. (2016). Season-long increases in perceived muscle soreness in professional rugby league players: role of player position, match characteristics and playing surface. *Journal of Sports Sciences*, 34(11), 1067-1072. doi: 10.1080/02640414.2015.1088166
- Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., . . . Dodge, C. (2001). A new approach to monitoring exercise training. *J Strength Cond Res*, 15(1), 109-115
- Frayn, K. N. (1983). Calculation of substrate oxidation rates in vivo from gaseous exchange. *J Appl Physiol Respir Environ Exerc Physiol*, 55(2), 628-634
- Goran, M. I., Poehlman, E. T., & Danforth, E., Jr. (1994). Experimental reliability of the doubly labeled water technique. *Am J Physiol*, 266(3 Pt 1), E510-515. doi: 10.1152/ajpendo.1994.266.3.E510
- Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*, 41(1), 3-13. doi: 10.1249/MSS.0b013e31818cb278
- Logue, D., Madigan, S. M., Delahunt, E., Heinen, M., Mc Donnell, S. J., & Corish, C. A. (2018). Low Energy Availability in Athletes: A Review of Prevalence, Dietary Patterns, Physiological Health, and Sports Performance. *Sports Med*, 48(1), 73-96. doi: 10.1007/s40279-017-0790-3
- Longland, T. M., Oikawa, S. Y., Mitchell, C. J., Devries, M. C., & Phillips, S. M. (2016). Higher compared with lower dietary protein during an energy deficit combined with intense exercise promotes greater lean mass gain and fat mass loss: a randomized trial. *Am J Clin Nutr*, 103(3), 738-746. doi: 10.3945/ajcn.115.119339
- Lundy, B., O'Connor, H., Pelly, F., & Catterson, I. (2006). Anthropometric characteristics and competition dietary intakes of professional rugby league players. *Int J Sport Nutr Exerc Metab*, 16(2), 199-213
- MacKenzie, K., Slater, G., King, N., & Byrne, N. (2015). The Measurement and Interpretation of Dietary Protein Distribution During a Rugby Preseason. *Int J Sport Nutr Exerc Metab*, 25(4), 353-358. doi: 10.1123/ijsnem.2014-0168
- Morehen, J. C., Bradley, W. J., Clarke, J., Twist, C., Hambly, C., Speakman, J. R., . . . Close, G. L. (2016). The Assessment of Total Energy Expenditure During a 14-Day In-Season Period of Professional Rugby League Players Using the Doubly Labelled Water Method. *Int J Sport Nutr Exerc Metab*, 26(5), 464-472. doi: 10.1123/ijsnem.2015-0335
- Naughton, M., Miller, J., & Slater, G. J. (2017). Impact-Induced Muscle Damage and Contact-Sport: Aetiology, Effects on Neuromuscular Function and Recovery, and the Modulating Effects of Adaptation and Recovery Strategies. *Int J Sports Physiol Perform*, 1-24. doi: 10.1123/ijsp.2017-0268
- Schoeller, D. A., & van Santen, E. (1982). Measurement of energy expenditure in humans by doubly labeled water method. *J Appl Physiol Respir Environ Exerc Physiol*, 53(4), 955-959
- Schoeller, D. A., van Santen, E., Peterson, D. W., Dietz, W., Jaspan, J., & Klein, P. D. (1980). Total body water measurement in humans with <sup>18</sup>O and <sup>2</sup>H labeled water. *Am J Clin Nutr*, 33(12), 2686-2693
- Silva, A. M., Santos, D. A., Matias, C. N., Minderico, C. S., Schoeller, D. A., & Sardinha, L. B. (2013). Total energy expenditure assessment in elite junior basketball players: a validation study using doubly labeled water. *J Strength Cond Res*, 27(7), 1920-1927. doi: 10.1519/JSC.0b013e31827361eb

- Smith, D. R., Jones, B., Sutton, L., King, R. F. G. J., & Duckworth, L. C. (2016). Dietary Intakes of Elite 14- to 19-Year-Old English Academy Rugby Players During a Pre-Season Training Period. *International Journal of Sport Nutrition and Exercise Metabolism*, 26(6), 506-515. doi: 10.1123/ijsnem.2015-0317
- Smith, D. R., King, R., Duckworth, L. C., Sutton, L., Preston, T., O'Hara, J. P., & Jones, B. (2018). Energy expenditure of rugby players during a 14-day in-season period, measured using doubly labelled water. *Eur J Appl Physiol*, 118(3), 647-656. doi: 10.1007/s00421-018-3804-4
- Southgate, D. A., & Durnin, J. V. (1970). Calorie conversion factors. An experimental reassessment of the factors used in the calculation of the energy value of human diets. *Br J Nutr*, 24(2), 517-535
- Thomas, D. T., Erdman, K. A., & Burke, L. M. (2016). American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. *Medicine and science in sports and exercise*, 48(3), 543-568. doi: 10.1249/mss.0000000000000852
- Till, K., Scantlebury, S., & Jones, B. (2017). Anthropometric and Physical Qualities of Elite Male Youth Rugby League Players. *Sports Medicine*, 47(11), 2171-2186. doi: 10.1007/s40279-017-0745-8
- Tooley, E., Bitcon, M., Briggs, M. A., West, D. J., & Russell, M. (2015). Estimates of Energy Intake and Expenditure in Professional Rugby League Players. *International Journal of Sports Science & Coaching*, 10(2-3), 551-560. doi: 10.1260/1747-9541.10.2-3.551
- Weaving, D., Sawczuk, T., Williams, S., Scott, T., Till, K., Beggs, C., . . . Jones, B. (2018). *The peak duration-specific locomotor demands and concurrent collision frequencies of European Super League rugby.*
- Westerterp, K. R. (2017). Doubly labelled water assessment of energy expenditure: principle, practice, and promise. *European Journal of Applied Physiology*, 117(7), 1277-1285. doi: 10.1007/s00421-017-3641-x