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International Journal of Sport Nutrition & Exercise Metabolism

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https://doi.org/10.1123/ijsnem.2024-0152

International Journal of Sport Nutrition and Exercise Metabolism, (Ahead of Print)
https://doi.org/10.1123/ijsnem.2024-0152

First Published Online: Nov. 28, 2024

Human Kinetics
ORIGINAL RESEARCH

The Contribution of Whole-Food and Supplemental Derived Dietary Protein, From Animal and Nonanimal Origins, to Daily Protein Intake in Young Adults: A Cross-Sectional Analysis

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We characterized daily dietary protein intakes, focusing on protein source (animal and nonanimal) and form (whole-foods and supplemental) in young (18–40 years) resistance trained (training ≥ 3×/week for ≥ 6 months; TRA; male, $n = 30$; female, $n = 14$) and recreationally active (no structured training; REC; male, $n = 30$; female, $n = 30$) individuals. Using 3-day weighed food diaries from 10 previous studies, we assessed macronutrient intakes using dietary analysis software. Energy intakes trended greater in TRA compared with REC ($p = .056$) and were greater in males than females ($p = .006$). TRA consumed greater ($p = .002$) proportions of daily energy intake as protein than REC (23 ± 6 vs. 19 ± 5%Energy), which also trended greater in males compared with females (22 ± 3 vs. 20 ± 2%Energy; $p = .060$). Absolute ($p < .001$) and relative (to body mass [BM]; $p < .001$) protein intakes were greater in TRA (males, 159 ± 54 g/day or 1.6 ± 0.7 g·kg^{-1} BM·day^{-1}; females, 105 ± 40 g/day or 2.0 ± 0.6 g·kg^{-1} BM·day^{-1}; $p < .001$) than REC (males, 103 ± 37 g/day or 1.3 ± 0.5 g·kg^{-1} BM·day^{-1}; females, 85 ± 23 g/day or 1.3 ± 0.4 g·kg^{-1} BM·day^{-1}; $p < .001$), with absolute ($p = .025$), but not relative ($p = .129$) intakes greater in males. A greater proportion of total protein was consumed from animal compared with nonanimal in TRA (68% vs. 32%, respectively; $p < .001$) and REC (64% vs. 36%, respectively; $p < .001$); the skew driven exclusively by males (72% vs. 28%, respectively; $p < .001$). A greater proportion (~92%) of total protein was consumed as whole-foods compared with supplemental, irrespective of training status or sex ($p < .001$). We show animal and whole-food–derived proteins contribute the majority to daily dietary protein intakes in TRA and REC young males and females.

Keywords: protein source, protein form, habitual intakes

The consumption of adequate dietary protein is essential for the preservation of skeletal muscle mass (Burd et al., 2019). For individuals involved in regular resistance exercise, dietary protein is a vital stimulus to increase muscle protein synthesis (MPS) rates. Over time, this promotes a positive muscle protein balance and therefore supports muscle hypertrophy and/or remodeling (Morton et al., 2018). Mechanistic research (Moore et al., 2009; Tipton et al., 1999) and applied interest (Monteyne et al., 2023; Stokes et al., 2018) have been directed at refining aspects of dietary protein nutrition to optimize MPS responses which, in turn, aims to improve muscle health, training adaptations, and performance outcomes.

The World Health Organization (WHO, 2007) recommended dietary allowance (RDA) for dietary protein is 0.8 g per kilogram body mass (BM) per day, assumed sufficient to prevent deficiency in the majority of healthy adults (Trumbo et al., 2002). However, for exercising individuals wishing to increase muscle mass and/or support muscle adaptive responses, intakes up to 1.6 g·kg^{-1} BM·day^{-1} have been shown to be more optimal (Morton et al., 2018). Currently, most data assessing habitual dietary protein intakes of young (active) individuals derive from studies examining total intakes, sex differences, and/or daily distribution across meals (Erdman et al., 2013; Gillen et al., 2017; Holm et al., 2008; Mamerow et al., 2014; Smeuninx et al., 2020).

Recent work has begun to assess the proportion of protein consumed from animal and nonanimal derived sources, motivated by nutritional factors relating to protein quality, as well as wider social applicability to sustainability and/or ethical issues (Hone et al., 2020). Though nonanimal derived proteins typically impose a lesser environmental and/or ethical burden (Ferrari et al., 2022), they generally possess less favorable (essential) amino acid profiles (Gorissen et al., 2018) and/or inferior digestibility (Hertzler et al., 2020). This implies that predominantly nonanimal-based diets may require greater (i.e., ≥1.6 g·kg^{-1} BM·day^{-1}) total protein intakes to support optimal adaptive responses to exercise (van Vliet et al., 2015; West, Monteyne, Whelehan, van der Heijden et al., 2023).

Aside from animal and nonanimal protein origin, an often-neglected consideration of a protein source is its existence as an isolate, or within a whole-food, and its unique matrix. Most mechanistic research to date has investigated isolated protein sources (e.g., Tang et al., 2009) despite the majority of protein being consumed in Whole-Food form (Garcia-Roves et al., 2000; Wardenaar et al., 2017). This is consequential, given emerging data suggest the presence of protein within a whole-food may influence the regulation of postprandial MPS rates compared to when consumed as a comparable protein isolate (van Vliet et al., 2017; West, Monteyne, Whelehan, Abdelrahman et al., 2023). To date, it is not clear what proportion of daily dietary protein intakes are obtained from whole-food versus isolated (commonly referred to and consumed as "supplemental" protein) sources originating from animal or nonanimal sources in (exercising) young adults.

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Such information is required to refine more contemporaneous practical recommendations for dietary protein intake in (active) young adults where consideration of protein origin is only becoming more relevant. In the present work, we conducted a detailed analysis of habitual dietary protein consumption in a large cohort of resistance trained (TRA) and recreationally active (REC) young individuals in the United Kingdom. The aim was to fully characterize dietary protein intakes between sexes and across meal moments with the focus being on source (i.e., animal vs. nonanimal) and form (i.e., whether consumed as whole-foods or (more) isolated supplemental forms) in TRA and REC individuals.

Methods

Study Population and Ethical Approval

Habitual dietary data were obtained from studies conducted within the University of Exeter's Nutritional Physiology Research Laboratories across 10 studies performed between 2018 and 2023 (Apicella et al., 2024; Haigh et al., 2024; Jameson et al., 2021; Pavis et al., 2022, 2023; van der Heijden et al., 2024; West, Monteyne, Whelehan, Abdelrahman et al., 2023; West, Monteyne, Whelehan, van der Heijden et al., 2023; Whelehan et al., 2024; Wilkinson et al., 2024). Studies were selected based on including young (18–40 years), healthy adults (resulting in $n = 104$) who were either TRA ($n = 44$; 14 females/30 males) or REC ($n = 60$; 30 females/30 males) from a predominantly Devon, United Kingdom, university-based, student cohort, with the associated socio/economic/ethnic demographics. As such, this represents a convenience sample from studies recruited to look at endpoints typical to studies of nutritional physiology and therefore lacks clear generalizability to be representative of the wider U.K. population. The studies also included some minor variations in inclusion criteria: protein intake < 0.8 g·kg^{-1} BM·day^{-1} and > 2.0 g·kg^{-1} BM·day^{-1} were excluded in some studies (Jameson et al. 2021, Pavis et al. 2022, Wilkinson et al. unpublished). The influence of these convenience sampling methods on the applicability of our data is addressed in more detail in the "Discussion" section. Participants were categorized as TRA if they participated in regular resistance exercise (≥3 times per week, for a minimum of 6 months at the time of data collection) and REC, if active, but not engaged in structured resistance or endurance exercise.

Participants' characteristics are presented in Table 1. All participants provided written informed consent within the individual study in which they participated. All individual studies received ethical approval from the University of Exeter's Sport and Health Sciences Ethics Committee and were registered on ClinicalTrials.gov (please see, NCT02980900, NCT03918395, NCT03934632, NCT06129513, NCT04894747, NCT04084652, NCT04084639,

Table 1 Participants' Characteristics and Habitual Dietary Intakes

	REC			TRA		
	Males ($n = 30$)	Females ($n = 30$)	Total ($N = 60$)	Males ($n = 30$)	Females ($n = 14$)	Total ($N = 44$)
Age (years)	22 ± 4	24 ± 5	23 ± 4	23 ± 5	25 ± 6	24 ± 5
Body mass (kg)	80 ± 12*	64 ± 10	71 ± 13	82 ± 8*	67 ± 8	77 ± 11
Height (m)	1.81 ± 0.06*	1.67 ± 0.08	1.74 ± 0.10	1.80 ± 0.07*	1.71 ± 0.06	1.75 ± 0.07
BMI (kg/m^2)	23.6 ± 3.0	23.2 ± 9.6	23.4 ± 3.0	25.3 ± 2.3	23.4 ± 3.1	24.7 ± 2.7
Habitual dietary intakes						
Energy intake (MJ/day^{-1})	8.8 ± 3.1*	8.3 ± 2.4	8.6 ± 2.8	11.1 ± 2.8*	8.3 ± 1.9	10.2 ± 2.9
Energy intake (kcal/day^{-1})	2108 ± 765*	1981 ± 586	2045 ± 90	2658 ± 727*	1984 ± 469	2321 ± 477
Carbohydrate intake (g/day)	218 ± 102	225 ± 68	221 ± 86	236 ± 109	197 ± 102	252 ± 77.8
Carbohydrate intake (%En)	41 ± 11	47 ± 13*	44 ± 12	40 ± 10	49 ± 18	43 ± 13
Fat intake (g/day)	73 ± 37	74 ± 27	73 ± 32	89 ± 45	61 ± 33	90 ± 35
Fat intake (%En)	31 ± 9	34 ± 9	32 ± 8	33 ± 8	35 ± 18	34 ± 12
Protein intake (g/day)	102 ± 37*	85 ± 23	94 ± 32	159 ± 54*,a,b,c	105 ± 40	143 ± 56^
Protein intake (%En)	20 ± 6	18 ± 5	19 ± 5	24 ± 6	21 ± 6	23 ± 6^
Protein intake (g·kg^{-1} BM·day^{-1})	1.3 ± 0.5	1.3 ± 0.4	1.3 ± 0.5	1.6 ± 0.7	2.0 ± 0.6	1.9 ± 0.7^
Animal protein (g/day)	70 ± 34*	50 ± 24	61 ± 31	118 ± 52*,a,b,c	53 ± 34	98 ± 56^
Animal protein (g·kg^{-1} BM·day^{-1})	0.9 ± 0.5*	0.8 ± 0.4	0.8 ± 0.5	1.4 ± 0.6*,a,b,c	0.9 ± 0.6	1.3 ± 0.7^
Animal protein (%total pro·day^{-1})	66 ± 20*	57 ± 20	62 ± 20	72 ± 16*	52 ± 24	66 ± 21
Nonanimal protein (g/day)	32 ± 17	35 ± 17	33 ± 17	41 ± 20	52 ± 47	45 ± 31^
Nonanimal protein (g·kg^{-1} BM·day^{-1})	0.4 ± 0.2*	0.5 ± 0.2	0.5 ± 0.2	0.5 ± 0.3	0.8 ± 0.6	0.6 ± 0.4^
Nonanimal protein (%total pro·day^{-1})	34 ± 20*	43 ± 20	38 ± 20	28 ± 16*	48 ± 24	34 ± 21
Protein from whole-food (g/day)	99 ± 36*	83 ± 24	91 ± 31	143 ± 48*,a,b,c	88 ± 31	126 ± 50^
Protein from supplementary (g/day)	3 ± 8	2 ± 5	3 ± 7	16 ± 19	17 ± 18	17 ± 19^

Note. Values are presented as mean ± *SD*. Data were analyzed using a two-way analysis of variance. BMI = body mass index; %total pro = % of total protein in grams consumed on average per day; %En = percentage contribution of energy consumed from each macronutrient to total energy intake; REC = recreationally active; TRA = resistance trained; BM = body mass.

Significance shown for main effects: *effect of sex ($p < .05$); ^effect of training status ($p < .05$). Significance shown for individual differences (Sex × Training status interaction): [a]significantly different compared with REC males ($p < .05$); [b]significantly different compared with REC females ($p < .05$); [c]significantly different compared with TRA females ($p < .05$).

NCT04794153, NCT04156386, NCT06268678) for individual ethical approval and clinical trials registration details). To characterize dietary information for the subject cohorts in these previously published papers, energy and macronutrient intakes were reported, but the present amalgamation of data represent a novel data set to investigate original research questions regarding the source and form of dietary protein consumed.

Dietary Intake Recording

Participants completed a habitual 3-day weighed food diary which included the consumption of food, beverage, and supplement intake across two consecutive weekdays and one weekend day. Researchers provided instructions on how to complete the food diary, setting expectations of what was required (timing, brand/type, amount [weighed cooked or raw], cooking preparation), to minimize underreporting and improve accuracy of measurements. This was applied uniformly across studies in line with the research group's protocols. Entries were handwritten in provided booklets or completed using a mobile app, MyFitnessPal, on the participants' request.

We acknowledge that there will be some degree of variability between researchers providing initial instructions to participants on how to complete the diet diaries, which cannot be changed. However, to reduce further variation, only two researchers performed the input of data, and a test–retest validation was used to assess the variation when inputting the data onto dietary analysis software (Nutritics). The test showed that the input of data differed by only 4.5% and 3.8% based on energy and protein intakes, respectively.

Determination of Energy and Macronutrient Intakes

For each participant, dietary intake was analyzed for nutritional content using dietary analysis software (Nutritics). Daily dietary intake was divided into six meal moments where identifiable (*Breakfast, a.m. snack, Lunch, p.m. snack, Dinner, and Late snack).* For each meal moment across the 3 days recorded, energy and macronutrient intakes were extracted into an Excel spreadsheet. Energy intake was expressed in megajoules per day and kilocalories per day, carbohydrate and fat intakes were expressed in g/day and %En (percent contribution of total energy intake), whereas dietary protein intake was expressed in grams per day, grams per kilogram of BM per day (relative to body mass), and %En.

For more detailed analyses of the source and form of protein consumed, the extraction of data from Nutritics allowed for the separation of animal- and nonanimal derived proteins and from whether protein was consumed as part of a whole-food or as a supplement. Protein source (animal and nonanimal derived) and protein form (whole-food and supplemental) were expressed as grams per day and grams per kilogram of BM per day and percent contribution of total protein intake per day (detailed in Table 1). Supplemental protein was defined as a source that had been modified/processed to extract the protein content, producing a concentrated protein source (≥70% of total mass as protein), whereas whole-foods were defined as anything other than what could be defined as supplemental protein (≤70% of total mass as protein).

The analyses of food products that contained both animal- and nonanimal derived proteins were conducted as follows: Using the ingredients list provided on the packaging, the source of each ingredient was determined (i.e., animal or nonanimal). Each of these ingredients were then converted into grams (from percentage of total product mass), with the respective protein content of each ingredient calculated, summated, and then cross-checked with total protein reported on the nutritional information for that product. Similarly, this was replicated for food products containing both Whole-Food and supplemental protein. For example, commercially available products, enriched with protein concentrates or isolates, were separated between protein derived from whole-foods, and protein enriched from protein concentrates, and isolates, which were then categorized as supplemental protein.

Statistical Analyses

Data analyses were performed using GraphPad Prism 10.0 (GraphPad Software). Data are presented as mean ± *SD* or as a percentage difference (%). For clarity, the term absolute within this manuscript refers to values measured in grams per day and the term relative refers to relative to *BM* (unless otherwise indicated; (grams per kilogram of BM per day). All values reported are averaged over the 3 days of dietary information recorded by the participant. Participants' characteristics were analyzed for differences by grouping according to sex and training status. To analyze sex and training status-based differences for energy, macronutrient, and dietary protein intakes (total, absolute, relative, source, and form) two-way analyses of variance (ANOVAs) were performed. Following these analyses, we then examined how protein source and form were consumed with respect to distribution across the day. For these analyses, three-way ANOVAs were applied with training status and meal moment included as factors, and separate tests run for protein source or form as the third independent variable. For all ANOVA tests, in the event of any main (source/form; meal moment; training status) or interaction effects, Tukey's post hoc tests were applied to locate individual differences. Pearsons's product–moment correlation coefficient was used to calculate the relationship between daily energy and protein intakes. Cohen's d effect size, was applied to any trending to significance ($p \le .05$) variables. Effect sizes of 0.2 are considered to be small, 0.5 medium, and 0.8 large.

Results

Participants' Characteristics

Data concerning participants' characteristics are presented in Table 1. Age did not differ between sexes (effect of sex; $p = .739$) or training statuses (effect of training status; $p = .439$). Males were taller (effect of sex; $p < .001$) and had a greater BM (effect of sex; $p < .001$) compared with females. There were no differences in height (effect of training status; $p = .214$) or BM (effect of training status; $p = .107$) between TRA and REC individuals. Body mass index did not differ between males and females (though a trend was observed; main effect of sex; $p = .059$, $d = 1.227$) nor with training status (effect of training status; $p = .109$).

Diet Composition

Participants' habitual daily energy and macronutrient intakes are presented in Table 1. Daily energy intake was greater in males compared with females (effect of sex; $p = .006$) and tended to be higher in TRA compared with REC individuals (effect of training status; $p = .054$, $d = 0.804$). To confirm the well-established

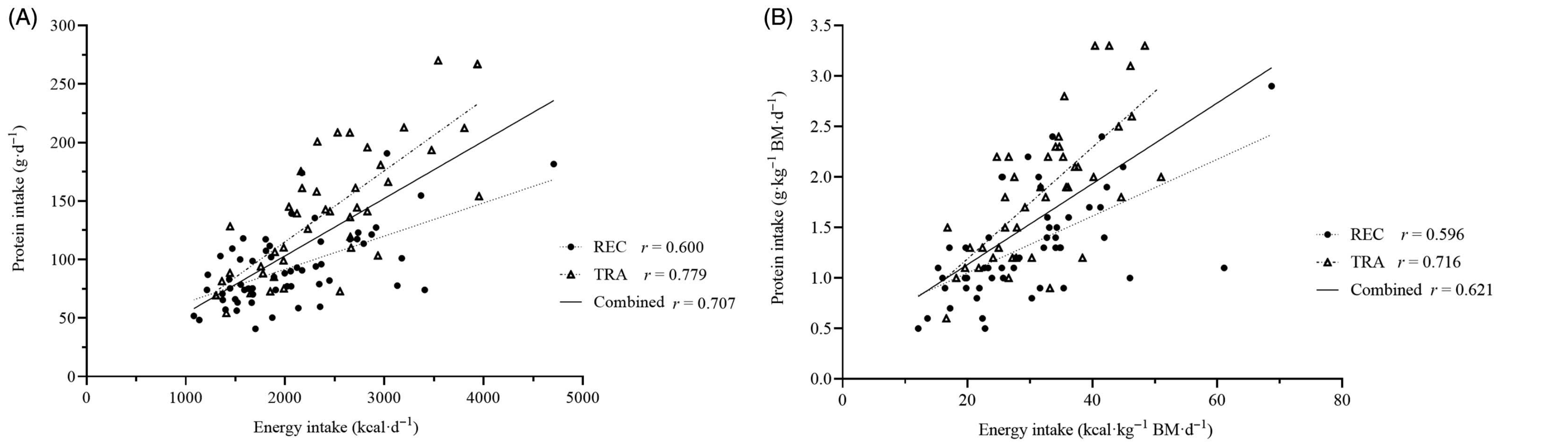

Figure 1 — Relationship between daily dietary protein and energy intake in REC ($n = 60$) and TRA ($n = 44$) individuals. (A) Correlation of absolute protein intake (in grams per day) and energy intake (in kilocalories per day) in REC ($r = .600$; $p < 0.001$), TRA ($r = .779$; $p < .001$), and combined ($r = .707$; $p < .001$). (B) Correlation of relative protein intake (to BM), protein intake (in grams per kilogram of BM per day), and energy intake (relative to BM; in kilocalories per kilogram of BM per day) in REC ($r = .596$; $p < .001$), REC ($r = .716$; $p < .001$), and combined ($r = .621$; $p < .001$). REC = recreationally active; TRA = resistance trained; BM = body mass.

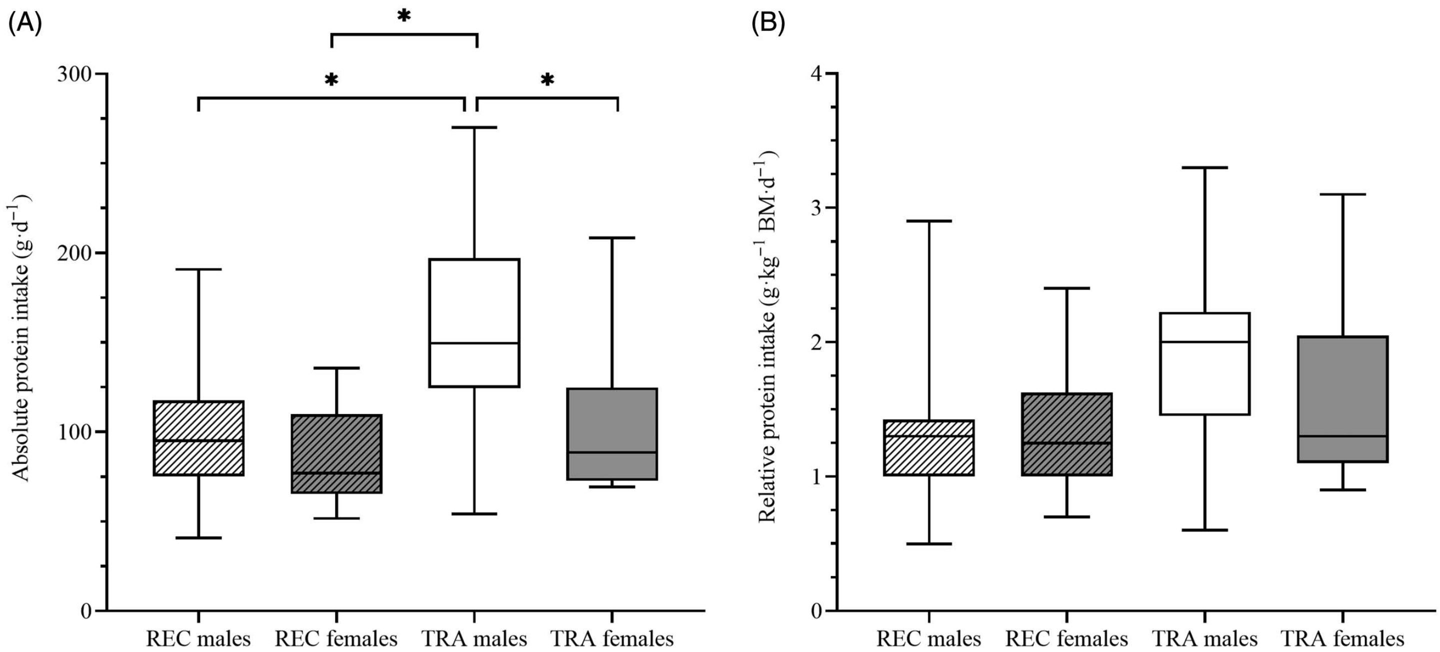

Figure 2 — Dietary protein intake in REC (male; $n = 30$, female; $n = 30$, total; $n = 60$) and TRA (male; $n = 30$, female; $n = 14$, total; $n = 44$) males and females. (A) Absolute protein intake (in grams), expressed as an average total over 3 days. (B) Relative protein intake (in grams per kilogram of BM), expressed as an average total over 3 days. Presented as a box and whisker plot, top and bottom of whiskers, displaying maximum and minimum values, respectively. Dietary protein intake (expressed as absolute and relative to BM) was analyzed using a two-way analysis of variance. For absolute protein intake, main effects of sex ($p = .025$) and training status ($p < .001$) and an interaction effect of Training status × Sex ($p = .001$) were identified. Tukey post hoc tests were used to detect differences between groups. For relative protein intake, there was a main effect of training status ($p < .001$), but not sex ($p = .129$), and no interaction effect of Training status × Sex ($p = .159$). Post hoc significance displayed, *significant difference between groups ($p < .05$). REC = recreationally active; TRA = resistance trained; BM = body mass.

Table 2 The Contribution of Animal and Nonanimal Derived Protein Sources to Daily Protein Intake (in Grams) Across Six Meal Moments in a Day

	REC		TRA	
	Ani	**Non-A**	**Ani**	**Non-A**
Breakfast	8 ± 8 (9%)	7 ± 5 (8%)	17 ± 13 (12%)	10 ± 7 (7%)
a.m. snack	1 ± 3 (1%)	1 ± 3 (1%)	5 ± 13 (4%)	3 ± 6 (2%)
Lunch	15 ± 12 (16%)	11 ± 8 (12%)	29 ± 25 (20%)	10 ± 8 (7%)
p.m. snack	4 ± 7 (4%)	2 ± 2 (2%)	6 ± 9 (4%)	4 ± 7 (3%)
Dinner	28 ± 17 (30%)	12 ± 8 (12%)	35 ± 26 (25%)	14 ± 11 (10%)
Late snack	4 ± 8 (4%)	1 ± 2 (1%)	5 ± 8 (3%)	3 ± 4 (2%)

Note. The average contribution of Ani (in grams) and Non-A (in grams)-derived protein to overall absolute protein intake across six meal moments in a day in REC ($n = 60$) and TRA ($n = 44$) individuals. Values are mean ± *SD*, and percentage of total daily protein intake is displayed as a mean in parentheses. Data were analyzed with a three-way analysis of variance, as reported in Table 4. With main effects of training status, meal moment source and interaction effects of Training status × Meal moment, Training status × Source, Meal moment × Form, and Training status × Meal moment × Source. Post hoc tests were applied to detect individual differences. Statistical significance for the three-way interaction of Meal moment × Training status × Source is shown in Table 4 and Figure 3A. Ani = animal; non-A = nonanimal; REC = recreationally active; TRA = resistance trained.

positive relationship between energy and protein intake (e.g., Gillen et al., 2017; Smeuninx et al., 2020), we first presented the relationship between these two dietary variables in our cohorts, expressed as absolute (Figure 1A) and relative (Figure 1B) protein intakes. Whether taking the cohort combined or subdivided for training status (TRA/REC), positive correlations (all $p < .001$) were observed between daily energy and (absolute or relative) protein intakes. Absolute carbohydrate and fat intakes did not differ depending on sex (effect of sex; $p = .492$ and $p = .068$, respectively) or training status (effect of training status; $p = .171$ and $p = .010$, respectively), though females consumed more carbohydrates as %EN compared with males (effect of sex; $p = .005$).

Absolute and relative dietary protein intakes are displayed in Figure 2. Absolute protein intakes were ~17% higher in males compared with females (effect of sex; $p = .025$) and ~41% higher in TRA compared with REC (effect of training status; $p < .001$). Individual differences showed TRA males consumed more absolute protein compared with REC males (Sex × Training status interaction; $p < .001$), REC females ($p < .001$), and TRA females ($p = .001$) (Figure 2A). Expressing as relative protein intakes

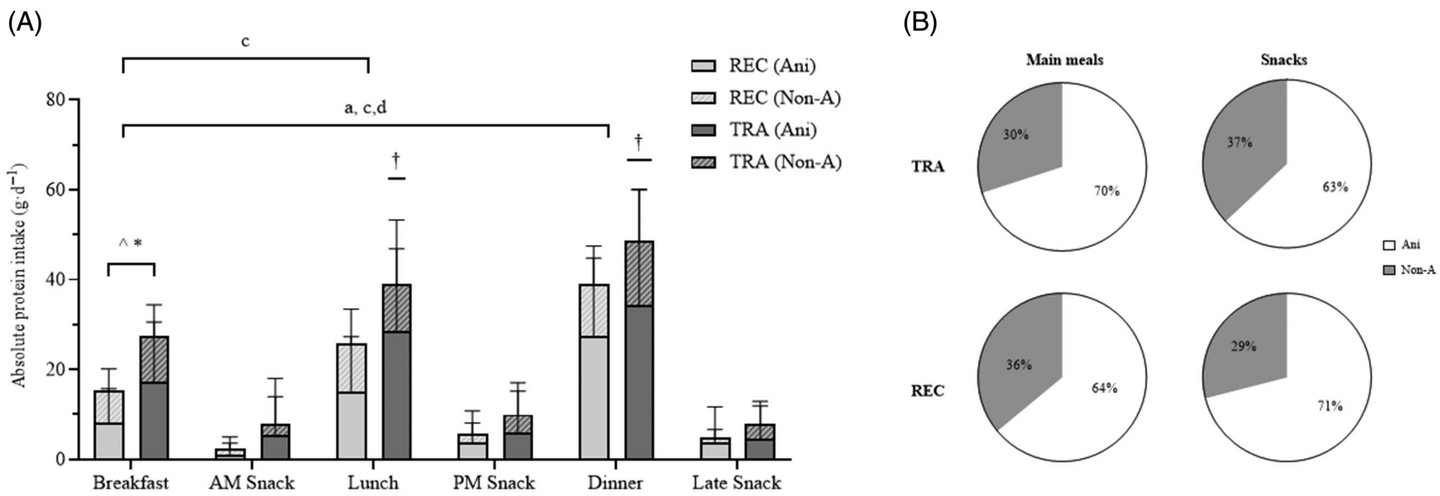

Figure 3 — The contribution of Ani- and Non-A-derived sources to total protein distribution in REC and TRA individuals. (A) Dietary protein distribution across six meal moments (breakfast, a.m. snack, lunch, p.m. snack, dinner, late snack), including contribution of Ani and Non-A protein sources to total absolute protein intake for REC ($n = 60$) and TRA ($n = 44$) individuals. Data were analyzed using a three-way analysis of variance (Meal moment × Training status × Source) and outcomes are reported in Table 4. Post hoc significance displayed. *Significant difference in the amount of Ani consumed between REC and TRA at a meal moment. ^Significant difference in Ani versus Non-A in REC individuals at a meal moment. †Significant difference in Ani versus Non-A protein in TRA individuals at a meal moment. [a]Significant difference in the amount of Ani consumed by TRA between meal moments. [c]Significant difference in the amount of Ani consumed by REC between meal moments. [d]Significant difference in the amount of Non-A protein consumed by REC between meal moments. (B) The percentage contribution of Ani and Non-A protein sources to total absolute protein intake at main meal (breakfast, lunch, and dinner) and snack moments (a.m. snack, p.m. snack, and late snack) for REC and TRA individuals. REC = recreationally active; TRA = resistance trained; Ani = animal; Non-A = nonanimal.

(Figure 2B) removed any sex-based differences (male: 1.6 ± 0.5 vs. female: 1.5 ± 0.2 $g \cdot kg^{-1}$ $BM \cdot day^{-1}$; effect of sex; $p = .129$); however, higher intakes in TRA compared with REC individuals remained (effect of training status; $p < .001$, though no Sex × Training interaction was detected, $p = .159$).

Training Status and Dietary Protein Distribution ("Meal Moment")

To allow the comparisons of meal moment as an additional variable and as the primary aim was to focus on training status, sex was removed from the following analyses as a statistical variable and analyses were performed on absolute protein intake only. Briefly, irrespective of training status, dietary protein intake was distributed differently across meal moments of the day, such that breakfast contained 20 ± 13 g/day, morning snack; 5 ± 11 g/day, lunch; 31 ± 20 g/day, p.m. snack; 7 ± 9 g/day, dinner; 43 ± 21 g/day, late snack; 6 ± 10 g/day (effect of meal moment; $p < .001$). The distribution of protein intake across the day did not differ between REC and TRA individuals (see Table 2 and Figure 3 [separated by source] and Table 3 and Figure 4 [separated by form]), apart from at two meal moments (Training status × Meal moment interaction; $p = .029$), such that at breakfast and lunch, TRA consume ~57% ($p < .001$) and ~33% ($p = .001$) more protein than REC, respectively. Statistical outputs for all comparisons (within the three-way ANOVAs) made in this section are reported in full in Table 4.

Dietary Protein Source: Animal and Nonanimal

Overall, more protein was obtained from animal than nonanimal sources (67% vs. 33%, respectively; $p < .001$), which was true in both TRA ($p < .001$) and REC ($p < .001$) individuals. The absolute amount of protein consumed from animal- or nonanimal derived sources differed between TRA and REC individuals (Training status × Source interaction; $p = .018$), such that TRA consumed more animal protein than REC (98 ± 56 vs. 61 ± 31 g/day, respectively; $p < .001$), but not more nonanimal protein (45 ± 31 vs. 33 ± 17 g/day, respectively; $p = .231$).

Irrespective of training status, protein obtained from animal or nonanimal sources differed depending on the meal moment (Meal moment × Source interaction; $p < .001$). More animal protein was consumed at dinner (30 ± 21 g/day) versus lunch (21 ± 20 g/day) versus breakfast (12 ± 11 g/day); however, there were no differences between snack moments ($p > .05$). Additionally, the amount of nonanimal protein only differed between dinner (13 ± 10 g/day) versus breakfast (8 ± 6 g/day) with no difference between snack moments ($p > .05$).

We then assessed the amount of protein consumed from animal compared with nonanimal derived sources at each meal moment (Meal moment × Source interaction; $p < .001$). More animal protein was consumed at breakfast (animal; 12 ± 11 vs. nonanimal; 8 ± 6 g/day; $p = .040$), lunch (animal; 21 ± 20 vs. nonanimal; 11 ± 8 g/day; $p < .001$), and dinner (animal; 30 ± 21 vs. nonanimal; 13 ± 10 g/day; $p < .001$) compared with nonanimal, with no differences at any snack moment (a.m., p.m., and late snack; $p > .05$). Finally, the source of protein consumed at each meal moment was also influenced by training status (Meal moment × Training status × Source interaction; $p = .002$). All P values are reported in Table 4 and post hoc significance is displayed in Figure 3.

Dietary Protein Form: Whole-Food or Supplemental

Overall, more protein was obtained from Whole-Food than supplemental protein sources (92% vs. 8%, respectively, $p < .001$; and at every meal; Meal moment × Form interaction; $p < .001$), which

Table 3 Contribution of Whole and Supp to Daily Protein Intake (in Grams) Across Six Meal Moments in a Day

	REC		TRA	
	Whole	Supp	Whole	Supp
Breakfast	14 ± 9 (15%)	0.9 ± 3.6 (1%)	22 ± 13 (15%)	5.8 ± 9.2 (4%)
a.m. snack	2 ± 4 (2%)	0.0 ± 0.0(<1%)	6 ± 15 (4%)	1.9 ± 4.4 (1%)
Lunch	25 ± 13 (27%)	0.5 ± 1.9 (1%)	39 ± 24 (27%)	0.4 ± 1.8(<1%)
p.m. snack	1 ± 2 (1%)	0.5 ± 1.9 (1%)	6 ± 7 (4%)	4.3 ± 8.4 (3%)
Dinner	39 ± 17 (42%)	0.1 ± 0.6 (<1%)	47 ± 26 (33%)	1.7 ± 6.1 (1%)
Late snack	4 ± 8 (4%)	0.5 ± 2.8 (1%)	6 ± 9 (4%)	1.5 ± 4.8 (1%)

Note. The average contribution of whole (in grams) and supp (supp) (in grams) to overall absolute protein intake across six meal moments in a day in REC ($n = 60$) and TRA ($n = 44$) individuals. Values are mean ± *SD*, and percentage of total daily protein intake is displayed as a mean in parentheses. Supp reported to one decimal place, due to lower values. Data were analyzed with a three-way analysis of variance, as reported in Table 4. With main effects of training status, meal moment, form, and interaction effects of Training status × Meal moment, Training status × Form, Meal moment × Form, and Training status × Meal moment × Form. Post hoc tests were applied to detect individual differences. Statistical significance for the three-way interaction of Meal moment × Training status × Form is shown in Table 4 and Figure 4A. REC = recreationally active; TRA = resistance trained; supp = supplemental protein; whole = Whole-Food protein.

was true in both TRA ($p < .001$) and REC ($p < .001$) individuals. The absolute amount of protein consumed from Whole-Food or supplemental protein differed between TRA and REC individuals (Training status × Form interaction; $p = .008$), such that TRA consumed more protein from whole-foods than REC (126 ± 50 vs. 91 ± 31 g/day, respectively; $p < .001$) and more from supplemental (17 ± 19 vs. 3 ± 7 g/day, respectively; $p = .05$).

Irrespective of training status, protein obtained from Whole-Food or supplemental protein differed depending on the meal moment (Meal moment × Form interaction; $p < .001$). When assessing the contribution of whole-food at a given meal moment, more protein in Whole-Food form was consumed at dinner (42 ± 22 g/day) versus lunch (30 ± 20 g/day) versus breakfast (18 ± 12 g/day), with no difference between snack moments ($p > .05$). The amount of protein consumed in supplemental form did not differ across meal moments ($p > .05$). Finally, the form of protein consumed at each meal moment was influenced by training status (Meal moment × Training status × Form interaction; $p < .001$). All p values are reported in Table 4 and post hoc significance is displayed in Figure 4.

Discussion

In the present work, we characterized dietary protein consumption throughout the day from differing sources (i.e., animal vs. nonanimal), and forms (i.e., whether consumed as whole-foods or (more) isolated forms; supplemental), and considered the influence of resistance training status and sex within young healthy adults. From this cohort, we report several findings consistent with previous literature. First, daily energy and protein intakes are strongly positively correlated. Second, males consume more protein than females, but only by virtue of a higher BM, whereas TRA individuals consume more protein even when adjusted for BM. Third, TRA individuals typically (~95% of cohort) consume well above the RDA for protein intake (0.8 g·kg^{-1} BM·day^{-1}) with the majority (~86% of cohort, exceeding lower; ≥1.2 g·kg^{-1} BM·day^{-1}; Phillips et al., 2007) or reaching higher (~63% of cohort; ≥1.6 g·kg^{-1} BM·day^{-1}; Morton et al., 2018) boundaries considered optimal within sports nutrition. Fourth, protein intake followed a skewed distribution throughout the day (breakfast [~20 g] < lunch [~31 g] < dinner [~43 g]) with snacks only providing about ~17% of daily protein. Our more novel findings include that overall animal derived proteins contributed the majority of daily protein regardless of training status; however, post hoc analyses revealed that this effect was primarily driven by males (~67%; vs. ~33% from nonanimal sources), and this was true across all individual meal moments. We also detail that the vast majority of protein was consumed within whole-foods (~92% of total daily protein) with the contribution of supplemental protein more prominent in TRA (compared with REC) individuals during snack moments (see Table 3 and Figure 4).

The consumption of adequate daily dietary protein and its timing and quality are all assumed crucial for skeletal muscle health and to support the optimization of the adaptive responses to prolonged resistance training (Morton et al., 2018). Our data show the average daily intakes are ~72% above the currently accepted RDA (0.8 g·kg^{-1} BM·day^{-1}). Individually, 95% of TRA and 92% of REC individuals, and 93% of males and 93% of females, exceeded the RDA, implying protein deficiency is not prevalent in this cohort. We acknowledge that the data obtained for this study was from a predominantly university-based location specific student cohort, which may have implications for providing a clear representation of the wider U.K. population of this age. However, our habitual daily intakes of Devon, United Kingdom-based recreational young adults are in line with similar data obtained from a Birmingham, United Kingdom-based cohort, which reported 98% of young individuals met the RDA (Smeuninx et al., 2020). Further agreement here is found within data reported in the National diet and nutrition survey from the U.K. government (Public Health England, 2020), which reported ~17% of total energy was consumed from protein in adults (19–64 years), comparable to our REC cohort (19%), with TRA individuals predictably consuming above this (23%), and greater than those observed in a well-trained Dutch cohort (18%; Gillen et al., 2017). A consideration potentially influencing our data is three of the included studies from where the present data set was obtained recruited REC individuals applying an exclusion criteria for protein intakes <0.8 g·kg^{-1} BM·day^{-1} and >2.0 g·kg^{-1} BM·day^{-1}. While this clearly has the potential to influence the overall data set, subanalysis of these studies revealed that relative protein intakes were similar to those of the overall cohort (1.2 vs. 1.3 g·kg^{-1} BM·day^{-1}, respectively), indicating any skew is likely to be modest. To optimize skeletal muscle adaptations to training and/or exercise performance, amounts of 1.2–1.6 g·kg^{-1} BM·day^{-1} are generally suggested (Morton et al., 2018; Phillips et al., 2007). We show that this target range was reached or exceeded in the vast majority of our cohort (~71%), and

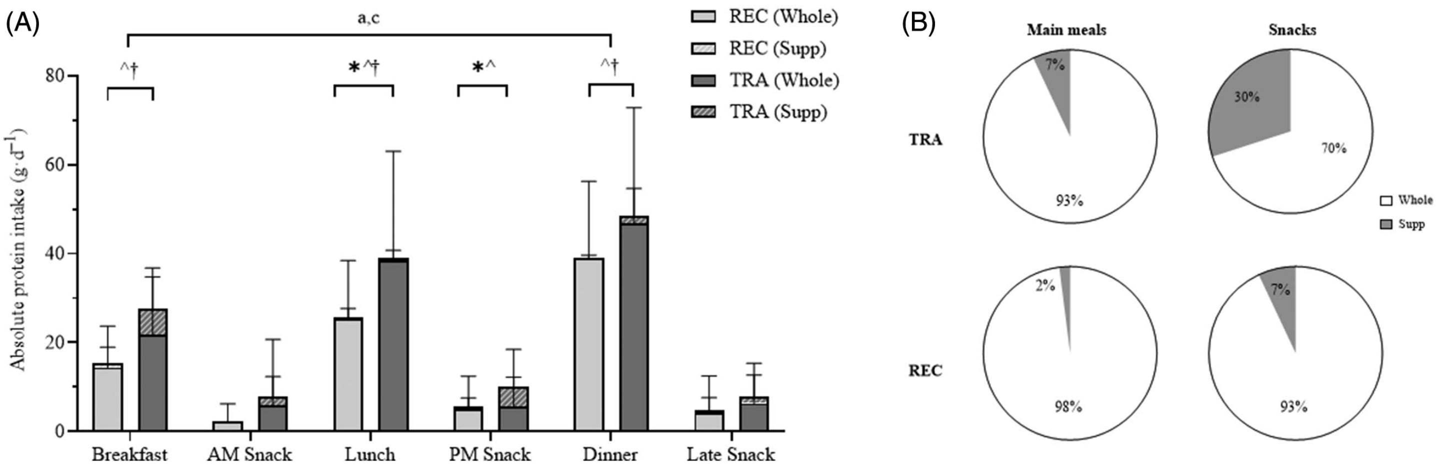

Figure 4 — The contribution of whole and supp to total protein distribution in REC and TRA individuals. (A) Dietary protein distribution across six meal moments (breakfast, a.m. snack, lunch, p.m. snack, dinner, and late snack), including contribution of whole and supp to total absolute protein intake for REC ($n = 60$) and TRA ($n = 44$) individuals. Data were analyzed using a three-way analysis of variance (Meal moment × Training status × Form) and outcomes are reported in Table 4. Post hoc significance displayed. *Significant difference in the amount of protein from whole consumed between REC and TRA at a meal moment. ^Significant difference in whole versus supp in REC individuals at a meal moment. †Significant difference in whole versus supp protein in TRA individuals at a meal moment. [a]Significant difference in the amount of protein from whole consumed by TRA between meal moments. [c]significant difference in the amount of protein from whole consumed by REC between meal moments; (B) The percentage contribution of whole and supp to total absolute protein intake at main meal (breakfast, lunch, and dinner) and snack moments (a.m. snack, p.m. snack, and late snack) for REC and TRA individuals. REC = recreationally active; TRA = resistance trained; supp = supplemental protein; whole = Whole-Food protein.

Table 4 Statistical Analyses of Habitual Protein Intake Reported as Absolute and Relative (to BM) Intakes for Source (Animal vs. Nonanimal) and Form (Whole-food or Supplemental)

	Training status, dietary protein distribution and protein source, animal and nonanimal						
	Training status	Meal moment	Source	Training status × Meal moment	Training status × Source	Meal moment × Source	Training status × Meal moment × Source
Protein intake (g/day)	$p < .001$	$p < .001$	$p < .001$	$p = .034$	$p = .018$	$p < .001$	$p = .002$
Protein intake (g·kg^{-1} BM·day^{-1})	$p < .001$	$p < .001$	$p < .001$	$p = .184$	$p = .120$	$p < .001$	$p = .018$
	Training status, dietary protein distribution and protein form; whole-food or supplemental						
	Training status	Meal moment	Form	Training status × Meal moment	Training status × Form	Meal moment × Form	Training status × Meal moment × Form
Protein intake (g/day)	$p < .001$	$p < .001$	$p < .001$	$p < .001$	$p = .052$	$p < .001$	$p < .001$
Protein intake (g·kg^{-1} BM·day^{-1})	$p < .001$	$p < .001$	$p < .001$	$p = .153$	$p = .163$	$p < .001$	$p = .115$

Note. Main (training status, meal moment, source [or form]) and interaction effects (Training status × Meal moment, Training status × Source [or Form], Meal moment × Source [or Form]) effects from three-way analyses of variance used to analyze differences in the contribution to total protein of animal and nonanimal protein sources and Whole-Food or supplemental protein across meal moments in a day (breakfast, a.m. snack, and lunch, p.m. snack, dinner, and late snack) in REC ($n = 60$) and TRA ($n = 44$) individuals. Protein intake expressed as grams per day; absolute protein intake in grams per day and grams per kilogram of BM per day; relative to BM protein intake in grams per day. REC = recreationally active; TRA = resistance trained; BM = body mass.

particularly so in those undertaking training (~86%). To a large extent, the higher protein intake in TRA individuals may be attributable to greater energy intakes and/or higher body mass (as is the case for males compared with females). However, this does not entirely explain the training-based differences, given that trained individuals also consumed higher relative protein intakes.

Mechanistic work has shown equally distributing dietary protein boluses (~≥20 g) throughout the day can optimize daily MPS rates compared with the same amount of protein consumed in a more typically skewed pattern (Areta et al., 2013; Mamerow et al., 2014), though long-term studies do not always confirm the assumed adaptive advantage (MacKenzie-Shalders et al., 2016). In the present work, we confirm previous findings (Gillen et al., 2017; Hone et al., 2020) that young adults consume their protein in a skewed manner, with dinner, lunch, and breakfast providing an amount of protein that likely robustly stimulates MPS (Moore et al., 2009). Snacks, on the other hand, provided an average of less than 8 g of protein over the day, a dose likely insufficient to measurably stimulate MPS rates, even if consumed in one sitting. A key finding of this study is that protein distribution differed between TRA and

REC individuals only at breakfast and lunch, where TRA consumed ~57% and ~33% more protein, respectively. This may be speculated to be attributed to food ingestion in close temporal proximity to training (Barutcu et al., 2020), a greater awareness of attempting better distributed protein intake (Devlin et al., 2017), or simply greater overall energy intake at breakfast and lunch.

Characterizing the origin of dietary protein has typically received less research attention but is fast becoming a contemporary priority. Societal priorities to reduce reliance on animal derived proteins (Ranganathan et al., 2016) can come into apparent conflict with sports nutrition guidelines, where nonanimal derived protein is often suggested to be inferior and may therefore require higher intakes (Tang et al., 2009). Furthermore, our mechanistic insight regarding sports nutrition guidelines has been obtained largely from studies investigating animal derived proteins (Elliot et al., 2006; Kim et al., 2015). In line with previous work (Hone et al., 2020), we observed that ~35% of dietary protein in our cohort was derived from nonanimal sources, but, interestingly, this did not differ between TRA and REC individuals. The latter point is somewhat surprising given it may be predicted that the protein density and high quality of animal derived proteins, and their prominence within sports nutrition guidelines, may make for a more attractive choice for TRA individuals. An interesting additional observation was the greater proportion of protein obtained from animal derived sources across groups was driven entirely by males (see Table 1). When the contribution of protein source is viewed per meal moment, TRA individuals consumed more of their protein from animal derived sources (compared with nonanimal) at lunch, and dinner, and was significantly more than REC at breakfast, an observation consistent with previous reports in a cohort of well-trained athletes (Gillen et al., 2017). Overall, however, it is clear that nonanimal derived proteins represent a substantial proportion of daily total protein intake at all meal moments across training statuses and sexes, warranting the growing current focus in more (mechanistic) research considering their anabolic potential.

Although animal proteins have been more widely studied in mechanistic work, this has been done almost exclusively (>75% of studies; Wilkinson et al., 2023) using isolated supplementary proteins. Recent work (e.g., van Vliet et al., 2017; West, Monteyne, Whelehan, Abdelrahman et al., 2023) is now beginning to address more complex, nutrient dense, and protein rich whole-foods, which comprise the vast majority of the diet, even in well-trained athletes (Gillen et al., 2017). In line with this, we detail (Table 3/Figure 4) that only ~8% of protein intake in our cohort came from supplemental protein, and this proportion was greater in TRA compared with REC, but not influenced by sex. Indeed, to a large extent, TRA individuals achieved their higher protein intakes by consuming more supplemental (at breakfast) *and* Whole-Food protein sources compared with REC. This was supported by TRA individuals consuming 30% of their total protein in supplemental form at snack moments compared to 7% in REC. Despite this apparent conscious effort to better balance protein intake across the day, our data still show that TRA individuals may still benefit from distributing their supplemental and Whole-Food protein more evenly over snacks moments.

The greater overall contribution of supplemental protein in TRA individuals can be speculated to be attributable to their belief of this as an ergogenic aid (Petróczi et al., 2007) and a convenient way of achieving higher protein intakes (Maughan et al., 2007). It is also worthy of note, that the protein density of supplemental protein also facilitates a greater relative energy intake from protein that we also reported in our TRA cohort. An important contextual point here, is how little we know about the regulation of MPS by protein-rich whole-foods, despite this comprising the vast majority of protein intake regardless of sex or training status. Recent work has begun to highlight how the food matrix, additional macronutrient or micronutrients, nutrient–nutrient interactions, and/or overall energetic load of whole-foods may influence protein digestion, absorption and/or muscle protein turnover. Our present data therefore shine a light on the need for future mechanistic and long-term work to address protein-rich, nutrient-dense whole-foods so the data underpinning modern sports nutrition guidelines can become more aligned with what is habitually consumed.

To conclude, we show that animal derived and Whole-Food protein contribute the majority to daily dietary protein intakes in TRA and REC young male and female. Given current (sports nutrition) dietary protein guidelines are underpinned primarily from studies investigating isolated (supplemental) animal derived proteins, more mechanistic studies to investigate protein-rich whole-foods from a range of sources are warranted.

Acknowledgments

Author Contributions: *Design:* Haigh, Stephens, Wall. *Data collection:* West, Whelehan, Pavis, van der Heijden, Wilkinson, Apicella, Dirks, Jameson. *Transferring of data from excel to Nutritics Software:* Haigh, N.P. *Contribution to inputting diet diaries and assistance in formatting the Excel spreadsheet:* Phillips. *Data analysis and interpretation:* Haigh. *Drafting of the manuscript with input from Monteyne and Wall:* Haigh. All authors approved the final version of the manuscript. This manuscript was made possible because of the research conducted within the Nutritional Physiology Group at the University of Exeter.

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