UPF RCT Protocol

Examining the causal impact of food processing level and nutritional composition on energy intake: a four-day randomised controlled trial

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BACKGROUND

Ultra-processed foods (UPF) are defined as "*formulations of ingredients, mostly of exclusive industrial use, typically created by a series of industrial techniques and processes*" (Monteiro et al., 2019a). For example, food products derived from industrial ingredients (such as high fructose corn syrup, interesterified oils, protein isolates, cosmetic additives) (Monteiro et al., 2019b; 2025). The Nova classification system groups foods based on the extent and purpose of processing; UPFs represent group four (Table 1) (Monteiro et al., 2019b). Key characteristics of UPFs include their low-cost ingredients, long shelf-life, convenience, hyper-palatability, minimal or no intact whole foods and they are common in UK diets (Monteiro et al., 2019a; 2019b; 2025).

Table 1. Nova classification system with relevant food-based examples (Monteiro et al., 2019a; 2019b).

Nova	Examples
Group 1 | Unprocessed & minimally processed foods*	Fruits, vegetables, grains, milk, eggs, herbs, spices
Group 2 | Processed culinary ingredients*	Vegetable oils, butter, sugar, honey, salt
Group 3 | Processed foods*	Legumes in brine, salted nuts, fruits in syrup, cheese
Group 4 | Ultra-processed foods	Confectionery, ice-cream, biscuits, ready meals

*Less processed foods (LPF): Nova group one to three.

To date, most of the research linking UPFs to negative health outcomes is from observational studies which show that higher UPF consumption is associated with adverse consequences including obesity, mortality, type 2 diabetes (Lane et al., 2024). Therefore, randomised controlled trials (RCT) are needed to establish causality (O'Connor et al., 2023; Monteiro et al., 2025). Recent RCTs are suggestive that UPF compared with less processed foods (LPF) can increase energy intake and body weight conducted in both laboratory and real-world settings with differing durations (one to eight weeks) (e.g., Hall et al., 2019; Hamano et al., 2024; Dicken et al., 2025; Preston et al., 2025, etc.). The mechanisms driving increased energy intake and weight gain from UPF diets are not fully understood; however, several have been

proposed, including nutrient imbalances, hyper-palatability, high energy density, soft texture and disrupted food structures (Monteiro et al., 2025). Sensory cues derived from texture have also been cited as a potential mechanism for UPF overconsumption (Teo et al., 2022; Lasschuijt et al., 2023; Forde et al., 2026). Current RCTs have not been closely matched for macronutrients between UPF and LPF diets resulting in energy density differences which can have a strong impact on daily energy intake (Robinson et al., 2022; Robinson and Forde, 2026). In addition, study menus in current RCTs have not used the same foods and/or components (at a meal-level) for comparisons between UPF and LPF (Rezende et al., 2026). Because of this it is unclear whether ultra-processing itself acts as a driver of overeating independent to nutritional profile. Therefore, the present RCT will examine the causal impact of ultra-processing and nutritional composition independently on energy intake by using closely matched UPF and LPF diets.

RESEARCH OBJECTIVES & HYPOTHESES

This RCT will utilise three diet arms to compare UPF (Nova group four) with LPF (Nova group one to three; unmatched and matched based on UPF nutritional profile) diets using the same foods and/or components (to address limitations from previous research) derived from commonly consumed foods in the UK (an example would be supermarket purchased vs homemade version of lasagne; see "Study Diets" for further information).

- **Population:** adults without obesity (age-range: 18 to 64 years; BMI: 18.5-29.9 kg/m^2) able to attend the University of Liverpool.
- **Experimental Conditions:** three diet arms: (1) UPF; (2) unmatched LPF; and (3) matched LPF derived from commonly consumed foods in the UK.
- **Outcome:** (i) primary: average daily energy intake; (ii) secondary: changes in appetite sensations; and (ii) additional: body weight, eating rate, diet liking and familiarity, food cravings, well-being, gut health and sleep.
- **Timeframe:** four-day testing period for each diet.

The primary objective will compare the effects of UPF and LPF (unmatched and matched) diets on energy intake (ad libitum). The working hypothesis is (i) UPF consumption (four-day diet) will lead to greater energy intake compared with unmatched LPF in line with current RCT findings (e.g., Hall et al., 2019; Hamano et al., 2024; Dicken et al., 2025, etc.); and (ii) UPF vs

matched LPF (four-day diet) will provide a directly comparable test with equivalent nutritional profile resulting in no energy intake differences between diets. The secondary objective will explore changes in appetite sensations (hunger, fullness, and thirst) between UPF and LPF diets; additional parameters (including body weight, eating rate, diet liking and familiarity, food cravings, well-being, gut health and sleep) will be measured to be able examine whether diets differ for these outcomes and if necessary, allow for them to be controlled for in sensitibity analyses.

STUDY DESIGN

The RCT will use a counterbalanced repeated-measures block design with three four-day diet arms (Figure 1). Participants will receive each diet followed by a one-week washout period[1] between testing periods to minimise carry-over effects. A minimum of one week washout is suitable given that our primary outcome is behavioural (energy intake) and short-term changes to food preference (e.g., reduced liking of meal type due to recent consumption) would not be predicted to persist after seven days (Robinson et al., 2013). Cohorts of participants will be randomly allocated within a block-based design[2] (five blocks with six diet orders: ABC, ACB, BAC, BCA, CAB, CBA) using a computer-generated sequence (RANDBETWEEN function, Microsoft Excel, version 16.106). If participant recruitment rate, drop-out or withdrawal from a cohort leads to an imbalance (between numbers of participants completing each diet orders). This will be rebalanced by recruiting more participants to complete the diet order of the missing participants. All main meals (breakfast, lunch and dinner; will be presented *ad- libitum* – "feel free to consume as much or little as you wish until feeling comfortably full") and consumed in individual cubicles (distraction-free environment), with no time limit, at the University of Liverpool Eating Behaviour Laboratory. Food boxes will be provided with snacks to be consumed [if desired] out-of-the-laboratory coupled with a diary to capture consumption of any non-study foods for compliance purposes. A four-day testing period [Monday to Thursday] balances feasibility and sensitivity to detect subtle differences between diets, as well as no likely biological mechanism exists for dietary compensation beyond this timeframe (Rolls et al., 2007; Haynes et al., 2020; Rogers

[1] but up to four-weeks to provide flexibility. The rationale is informed from previous UPF trials (range: none to four-weeks) and balancing participant burden with sufficient time to mitigate potential carryout effects (primary outcome - energy intake) from preceding testing period (Lichtenstein et al., 2021; Tien et al., 2024).

[2] random number allocation between 1 and 30 then assigned to one of five participant blocks with six possible sequences.

& Brunstrom, 2016; Robinson et al., 2023). In addition, energy intake differences between UPF vs LPF diets in previous RCTs (Hall et al., 2019; Hamano et al., 2024) were observed between days one to four and effects across the full trial were comparable to at 4 days (cumulative).

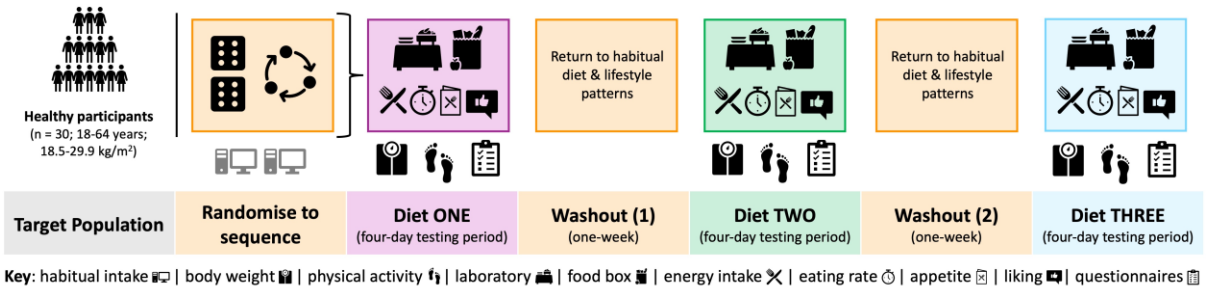


Figure 1. Overview of RCT study design.

The RCT received University of Liverpool ethical approval [Committee D – reference: 18294] in accordance with the Declaration of Helsinki, as well as will be pre-registered with International Standard Randomised Controlled Trial Number (ISRCTN) and open access repository (Zenodo). The study design and reporting will adhere to the Consolidated Standards of Reporting Trials (CONSORT) statement (Hopewell et al., 2025).

PATIENT & PUBLIC INVOLVEMENT

Patient and public involvement (PPI) contributors will provide input on the study design (including washout period, test menu, recruitment strategy), public facing materials and dissemination plans.

PARTICIPANTS

Participants (age-range[3]: 18 to 64 years; body mass index (BMI[4]): 18.5-29.9 kg/m^2) able to attend the University of Liverpool will be invited to take part in accordance with the inclusion criteria. We will attempt to stratify recruitment to balance (50:50) across age[5] (18-39 and 40-64), sex[6] (assigned at birth; male and female) and socioeconomic status (education[7]; National Qualifications Framework (NQF) Level 3 or below and NQF Level 4 or above) for representativeness of the UK population (ONS, 2023a; 2023b; GOV UK, 2025). If recruitment

[3] rationale – keep broad for recruitment purposes.
[4] approximately 68% of the UK population are within this range (NHS, 2026).
[5] under 25 (29.1%), 25-39 (20.2%), 40-59 (26.3%) and 60+ (24.4%) (ONS, 2023a).
[6] 51% female (ONS, 2023b).
[7] 50% of 19-64 years with NQF Level 4 or above (GOV UK, 2025).

is proving challenging for certain groups (lower SES, males) then some flexibility (40:60) will be applied; for example, prioritising lower SES (education) over age and sex. Participants will be informed that the study is about "*exploring the effects of diet on health*" to reduce demand characteristics in line with best practice (Robinson et al., 2018).

Inclusion Criteria

- aged 18 to 64 years.
- BMI between 18.5 and 29.9 kg/m^2.
- read and speak English fluently.
- willing to travel to the University of Liverpool.

Exclusion Criteria

- dislike and/or not willing to consume study meals (reviewed during in-person screening and rate dislike [<4] on 9-point hedonic scale for any meal components).
- food allergies, intolerances or dietary requirements which cannot be adhered to due to study foods.
- chronic conditions (e.g., diabetes, cancer, gastrointestinal disorders, kidney/liver disease, etc.), poor oral health (including difficulties with eating/swallowing) or cognition impairments impacting memory (such as dementia).
- history or current eating disorders and/or restrictive eating (including for religious reasons).
- following a weight-loss diet and/or not weight stable (5% change in past three months).
- current or recent smoker (including any tobacco, e-cigarettes, nicotine replacement therapy use in the past three months).
- pregnant or breastfeeding.
- not regularly consuming three meals per day.
- medication impacting study outcomes (including appetite, food intake, body weight, taste). This will be reviewed for potential side effects on a case-by-case basis using the National Institute for Health and Care Excellence (NICE) British National Formulary (BNF) (https://bnf.nice.org.uk/drugs/). For example, medications and/or drugs for weight loss (e.g., Wegovy, Mounjaro, etc.), psychotropic (e.g., olanzapine, mirtazapine, etc.) and endocrine (e.g., systemic glucocorticoids, etc.).

- unwilling to avoid drinking excessive amounts of alcohol (e.g., more than 14 units) per week (NHS, 2022; 2025) during the three four-day testing periods.
- unwilling to refrain from too much strenuous exercise (e.g., > 4 hours per week – that requires you to breathe hard and fast) during three four-day testing periods and/or not follow an exercise routine similar to their habitual exercise habits during active study weeks.
- participating in another research study involving food or alcohol consumption.
- unable (or unwilling) to adhere to study requirements.
- habitual intake considered implausible (24-hr recall) (female: 500-3500 kcal/d and male: 800-4000 kcal/d) (Willett, 2013).

Participants will be recruited via the following approaches:

- research group participant databases.
- University of Liverpool mailing lists (outside Psychology).
- word of mouth.
- social media.
- online noticeboards/groups and recruitment sites.
- posters distributed on campus and local area.
- paid advertisements.

The reimbursement rate for participation (upon study completion of three diet arms) will be £300 in the form of a bank transfer.

STUDY DIETS

The three diet arms (Table 2) will be presented *ad-libitum*[8] (breakfast, lunch, dinner, snacks):

- **Diet One – UPF**: comprising of UPF purchased food or meal (Nova: group four) commonly consumed in the UK diet – example: a supermarket lasagne ready meal.
- **Diet Two – unmatched LPF**: a less processed (Nova: group one to three) homemade version of selected UPF with lower energy density (≤0.50 kcal/g) between UPF and unmatched LPF) – example: a lasagne made using a recipe adapted from diet three

[8] the presented serving size of each meal was determined by a minimum of 2.5 times the recommended portion and considered large enough in volume that the majority of the population would not come close to consuming in full. Overall, diet one and three is scaled to around 5000 calories; therefore, at least 2x Eatwell Guide (OHID, 2024).

(e.g., more vegetables, less pasta without any UPF ingredients). This will enable a direct comparison with previous laboratory studies showing effects of UPF compared with LPF on daily energy intake: (i) Hall et al. (2019): 1.00kcal/g and (ii) Hamano et al. (2024): 0.90kcal/g. Therefore, meals will aim to be within a range from 0.50 to 1.00 kcal/g difference.

- **Diet Three – matched LPF**: a less processed (Nova: group one to three) homemade version of the selected UPF with equivalent nutritional composition [meal-level per 100g] (key nutrients [including energy, fat, carbohydrates, fibre, protein and salt]: <10% and energy density: <5%) – example: a lasagne made by manipulating vegetable [mushrooms], pasta [courgettes], cheese [cauliflower], butter [oil] and beef mince ratios from diet two to increase energy density and fat content to match the UPF version. The rationale for is to address limitations of previous research as diets typically have not been closely matched for nutritional profile (Robinson et al., 2026).

The nutritional composition of all test meals will be quantified from back-of-pack information and if unavailable will use the McCance and Widdowson's Composition of Foods Integrated Dataset (PHE, 2021). This will be externally tested by an accredited laboratory (e.g., Eurofins, Wolverhampton, UK) using validated nutritional methods [Group 1+2] at different time-intervals (pre and mid testing period) to ensure consistency during data collection and confirmation of expected macronutrient profile.

The energy contribution (kcal) from Nova 4 for diet one [UPF] aims to consist of >90% and for diet two/three (consistent with previous studies) where the majority of energy from Nova 1 (i.e., >50% energy) and comparable between the two (i.e., <10% of energy difference). For Nova 2 and 3, it is anticipate diets two and three to also be broadly similar, but because of the requirement to match diets for energy density, there will likely be small differences between diets in energy contribution from Nova 1-3. This approach will compare a diet that is almost completely derived from UPF (as in previous studies) with a diet that is predominantly derived from LPF and similar for energy density, and a diet that is also mainly derived from LPF but lower in energy density (as in previous studies). Consistent with our study objectives, contrasts will therefore reveal what impact on energy intake predominantly UPF vs. LPF diets have, under conditions of matched and unmatched energy density.

Study Diet Criteria

- **Criteria 1** – all food items will be commonly consumed in the UK diet (defined by being readily available at one or more of the Big-Four Supermarkets: Tesco, Sainsburys, ASDA and Morrisons). In addition, selected snacks will be regularly consumed based on National Diet and Nutrition Survey (NDNS) data and market research reports (Mintel, Statista, YouGov); confectionery (sugar, chocolate), biscuits (sweet, savoury), crisps and cakes (including buns, pastries) were considered key categories (Amstrong, 2022; Caines, 2025; OHID, 2025).
- **Criteria 2** – familiar, reproducible and homemade versions of UPFs can be created from online recipes or books to enable meal-level comparison (e.g., UPF and LPF lasagne) between diets.
- **Criteria 3** – meals can be classified as UPF or LPF in accordance with the Nova criteria and best practice. Initially, commercial foods or ingredients will be reviewed on the "OpenFoodFacts" app [https://world.openfoodfacts.org] to confirm status[9] as marker of ultra-processing. Two independent coders from two research teams (Liverpool n = 2 and Imperial n = 2) will code each meal; conflicts will be resolved via discussion and additional coders for discrepancies (Monteiro et al., 2019; Martinez-Steele et al., 2023). Common identifiers of UPFs include: (1) **sugars** (free, as opposed to naturally containing) such as fructose, high-fructose corn syrup, fruit juice concentrates, invert sugar, maltodextrin, dextrose, lactose and modified starches; (2) **modified oils** such as hydrogenated or interesterified oils; (3) **proteins** sources such as hydrolysed proteins, soya protein isolate, gluten, casein, whey protein and mechanically separated meat; and (4) **additives** with cosmetic functions such as flavours, flavour enhancers, colours, emulsifiers, emulsifying salts, sweeteners, thickeners, anti-foaming, bulking, carbonating, foaming, gelling and glazing agents (Monteiro et al., 2019); therefore, selected UPFs will vary in types to reflect the broad range within the Nova group four classification.
- **Criteria 4** – nutritional composition can be matched at a meal-level: (i) UPF vs unmatched LPF will be ≥50% difference in energy density but the overall diet will be within the range of 0.50 to 1.00kcal/g to be consistent with previous research; and (ii)

[9] if not available on Open Food Facts then "The Food App" [https://www.thefood.app/uk] will be used.

UPF vs matched LPF meals will be nutritionally equivalent [meal-level per 100g] based on: (a) <10% for key nutrients [including energy, fat, carbohydrates, fibre, protein, salt] and (b) <5% for energy density to address limitations of current RCTs.

- **Criteria 5** – positive feedback on test menus based on PPI insights.
- **Criteria 6** – meals can be presented with same portion size (grams) and piloting indicates similar liking between diets.

Study Menu

The three diet arms (UPF, unmatched LPF, and matched LPF) will be presented adhering to six counterbalanced orders (one of six possible sequences within each five participant blocks: ABC, ACB, BAC, BCA, CAB, CBA); a list of pre-approved fluids (e.g., water, coffee, tea, etc.) will also be provided. The following meals are currently being considered for RCT inclusion and will be served with 500mL of water:

- **Breakfast** – porridge, granola + yoghurt and muesli + milk.
- **Lunch** – tomato basil pasta, macaroni cheese, pizza and quiche.
- **Dinner** – chilli con carne + rice, stir fry, creamy pasta and lasagne.
- **Dessert** – banana loaf, pancakes + ice-cream, lemon loaf and rice pudding.
- **Snacks** – shortbread, cookies, flapjack and popcorn.
- **Fixed**[10] – fruit [apple, grapes], vegetables [green beans, carrot, broccoli + sweetcorn, lettuce] and savoury [crisps, breadsticks] options.
- **Back-up**[11] – chicken tikka + rice, chicken wrap, flavoured crisps and blueberry muffins.

Based on pilot testing a final menu (Table 3) will be selected in line with the pre-defined diet criteria. Relevant back-up options will be identified in case of stock issues (e.g., alternative brand or supermarket options with similar nutritional composition). All food preparation will be conducted in accordance with Good Manufacturing Practice and appropriate risk analysis (including HACCP: Hazard Analysis and Critical Control Point) as well as being prepared by individuals with a Level 2 Certificate in Food Safety and Hygiene. All ingredients and meals will be documented in an inventory spreadsheet with date of purchase, storage requirements

[10] to address concerns from PPI about lack of diet variety – various fruit, vegetable and savoury options have been included. The resulting items will be fixed across all three diets.

[11] in case of supply chain issues – all main meals will have a reserve and additional options listed above can be rotated in (if unavailable or out-of-stock for a prolonged period).

(including location, disposal date), batch numbers and any relevant comments. All meals will be prepared adhering to individual SOP (three versions per meal) and pre-defined serving instructions.

Table 2. Example overall diet summary [including all snacks and fixed options].

Nutritionals[1]	Diet One [UPF]	Diet Two [unmatched]	Diet Three [matched]
Energy (kcal)	5240	3623	5222
Fat (g + %)	183.2 | 31.5%	87.6 | 21.8%	184.7 | 31.8%
Saturated fat (g + %)	55.1 | 9.5%	19.6 | 4.9%	53.7 | 9.3%
Carbohydrates (g + %)	707.4 | 54.0%	564.3 | 62.3%	706.6 | 54.1%
Total sugars (g +%)	216.8 | 16.6%	171.7 | 198.0%	223.2 | 17.1%
Fibre (g)	63.0	54.5	63.5
Protein (g + %)	155.3 | 11.9%	118.1 | 13.0%	150.4 | 11.5%
Salt (g)	10.3	5.6	10.1
Energy density (kcal/g)	1.78	1.23	1.77
Total serve (g)	2961	2961	2961
Nova Contribution[2]			
Group 1	1.7	67.3	60.3
Group 2	0.0	18.4	26.5
Group 3	3.9	14.3	13.2
Group 4	94.4	0.0	0.0

Data[1] is average from four-days and includes all meals, snacks and fixed options (n = 38 per diet). The calories per day vary by diet: diet one [5052-5389kcal], diet two [3396-3889kcal] and diet three [5049-5341kcal] with same serving size [g; amount of food presented] between 2768 to 3360g. The energy density difference [at a day level] is between 0.50 and 0.59kcal/g. The Nova contribution[2] from % energy [kcal] reflects the weighted average from each meal and ingredient.

Note: The exact nutritional profile and Nova characterisation of diet is estimated prior to trial delivery and final estimates will therefore be subject to minor change during delivery (e.g., a UPF product becoming unavailable and being replaced with a different back-up project). The nutritional profile of the three diets results in diet one and three being closely matched on all nutrients and overall energy density. As planned, diet two is lower in energy density than diet one and three and as in previous trials of UPF (Hall, Hamano) energy density reduction for diet two is primarily achieved through reductions in fat (vs. carbohydrate) ratio, whilst also retaining similar protein ratios. Dietary formulation to reduce energy density in diet two has also resulted in having less salt than diet one and three, as well as a small difference in fibre (e.g., replacement of dried banana in diet three with fresh banana for diet two to reduce energy density and fibre). Previous trials have similarly not matched for salt and fibre when comparing UPF diet vs. a less energy dense LPF diet. Diet two having an overall lower energy density, alongside less salt and slightly less fibre would not compromise our ability to replicate results of previous RCTs (i.e., lower energy intake for LPF diet vs. UPF), as lower salt tends to

decrease (as opposed to increase) energy intake and differences in fibre served would have negligible effects on energy intake as fibre primarily operates on short-term energy intake via energy density. Consistent with our hypotheses and the results of previous RCTs, based on overall energy density and nutritional profile of diets we would predict that daily energy intake for diet two (unmatched LPF) will be lower than diet one (UPF).

Based on final diet composition, in the present study we will compare a diet that is very high in UPF (94.4% Nova 4, 1.7% Nova 1) with diets that are predominantly derived from minimally processed foods (0% Nova 4, 60.3-67.3% Nova 1). This pattern is consistent with the approach adopted in the previous trials by Hall and Hamano, but a difference in our trial is that the LPF diets also include energy from Nova 2 (18.4-26.5%) and 3 (13.2-14.3%) categories. This was required to be able to compare like-for-like food products and enable energy density matching. Therefore, results of this RCT will provide information of the effects on energy intake of a diet very high in UPF vs. diets that are predominantly minimally processed foods alongside processed culinary ingredients and foods.

Historic estimates of UK diet suggest it is derived predominantly from Nova 4 (~55%) and then Nova 1 (~30%), 3 (~9.6%), 2 (~3.7%) (Rauber et al., 2019; Madruga et al., 2023). In this context, our RCT examines a UPF diet that is substantially higher in UPF (94.4%), substantially lower in minimally processed food (MPF) (1.7%) and somewhat lower in processed ingredients/foods (3.9%) than UK average. This UPF diet will be compared with LPF diets (matched and unmatched) that are substantially lower in UPF, higher in MPF and somewhat higher in processed ingredients/foods (than the UK average.

Table 3. Example study menu by day with proposed serving size, calories (kcal per serve) and key UPF markers.

Day	Meal	Food + Serving Size	Kcal [UPF]	Key UPF Marker [Open Food Facts and/or The Food App]
Monday	Breakfast	Muesli [250g] + milk [375mL]	915 + 124	Flavouring
Tuesday	Breakfast	Granola [250g] + yoghurt [450g]	1073 + 441	Flavouring
Wednesday	Breakfast	Porridge [600g]	710	Flavouring
Thursday	Breakfast	Muesli [250g] + milk [375mL]	915 + 124	Flavouring
Monday	Lunch	Macaroni cheese [840g] + green beans [80g]	991 + 39	Flavouring + maltodextrin + whey powder + colour
Tuesday	Lunch	Tomato basil pasta [800g] + salad [80g]	1200 + 11	Emulsifier + modified corn starch + flavouring + colour
Wednesday	Lunch	Pizza [500g] + salad [80g]	1200 + 11	Maltodextrin + dextrose
Thursday	Lunch	Quiche [400g] + salad [80g]	1012 + 11	Palm oil + colour
Monday	Dinner	Stir fry [750g]	1373	Stabiliser + flavouring + colour + thickener + paprika extract
Tuesday	Dinner	Chilli con carne + rice [960g] + vegetables [80g]	1170 + 26	Modified maize starch + flavouring + colour + stabiliser
Wednesday	Dinner	Creamy vegetable pasta [1125g]	1474	Dextrose + whey powder + milk proteins
Thursday	Dinner	Lasagne [925g] + salad [80g]	1119 + 11	Colour + flavouring
Monday	Desserts	Banana loaf [220g]	799	Flavouring + colour + stabiliser
Tuesday	Desserts	Rice pudding [500g]	745	Flavouring
Wednesday	Desserts	Lemon loaf [240g]	948	Glucose syrup + flavouring + emulsifier + gelling agent
Thursday	Desserts	Pancakes [240g] + ice-cream [160g]	636 + 234	Flavouring + emulsifier +whey powder + glucose syrup + palm oil + dextrose + emulsifier + stabiliser + flavouring + colour
Monday	Snack box	Shortbread [150g] + apple [133g] + chips [50g]	753 + 74 + 237	Flavouring
Tuesday	Snack box	Flapjack [120g] + grapes [80g] + breadsticks [40g]	502 + 54 + 168	Partially inverted sugar syrup + glucose syrup
Wednesday	Snack box	Cookies [160g] + apple [133g] + chips [50g]	741 + 74 + 237	Palm oil + partially inverted sugar syrup + emulsifier + flavouring
Thursday	Snack box	Popcorn [108g] + grapes [80g] + breadsticks [40g]	546 + 54 + 168	Emulsifier

MEASURES

Demographics

Participants will be characterised by: (1) **sex** (female, male); (2) **age** (years); (3) **ethnicity** (Asian or Asian British, Black, Black British, Caribbean or African, Mixed or Multiple Ethnic Groups, White, Other Ethnic Group); (4) **BMI** (calculated from screening: height and weight); (5) **education** (less than high school (no formal qualifications), high school completion (GCSEs or equivalent), college or foundation degree (A Levels or equivalent), bachelor's degree, master's degree, doctorate or professional degree); and (6) **employment status** (full-time, part-time, student, retired, unable to work due to sickness/disability, looking after home/family, unemployed, other).

Habitual Dietary Intake

Why: considered best practice to measure habitual intake for characterisation of recruited cohort in RCTs (Lichtenstein et al., 2020).

How: multiple 24-hour recalls via Intake24 (https://intake24.org) an open-source, validated web-based dietary assessment tool (Bradley et al., 2016; Foster et al., 2019). Quantify UPF intake by applying the Nova food classification based on previous research in line with best practices (as described above) (Monteiro et al., 2019; Chang et al., 2023).

Data: habitual intake of two non-consecutive 24-hour recalls: weekday (screening) + weekend (day before first testing period); UPF intake will be expressed as % of food intake coupled with daily energy intake.

Out-of-Range: data considered implausible will be excluded in accordance with non-individualised cut-offs (female: 500-3500 kcal/d and male: 800-4000 kcal/d) (Willett, 2013).

Primary Outcomes

Energy Intake

Why: understand variations in energy intake between diets – UPF consumption compared with LPF can lead to higher energy intake (e.g., Hall et al., 2019; Hamano et al., 2024; Dicken et al., 2025, etc.)

How: weighing (pre-post consumption) (i) all meals and (ii) snacks from food boxes, in duplicate (grams) (Tien et al., 2024). This will be subsequently converted to derive an energy

intake (kcal): food consumed (grams) x energy density (kcal/g) (informed from pre-determined nutrition composition and relevant software).

Data: daily energy intake (kcal/d) + amount consumed (grams) from four-day testing period for each diet (calculated at meal, day and week level).

Secondary Outcomes

Appetite

Why: understand variations in subjective appetite ratings between diets – similar appetite sensations (hunger/fullness) have been reported in previous RCTs; however, limitations remain over nutritional matching (e.g., Hall et al., 2019; Lasschuijt et al., 2023; Hamano et al., 2024; Dicken et al., 2025; Rego et al., 2025, etc.).

How: visual analogue scales (VAS; 0-100) on hunger, fullness and thirst pre-post each meal consumed in the laboratory (Flint et al., 2000) (Appendices, Figure A1).

Data: average subjective appetite ratings pre-post meals (breakfast, lunch, dinner) from four-day testing period for each diet. The area under the curve (AUC) will be calculated for each appetite sensation per day (breakfast, lunch, dinner; pre-post meal ratings) and compared across diets using the trapezoid function (Pruessner et al., 2003; Blundell et al., 2010).

Additional Outcomes

We will measure a number of additional outcomes which could theoretically differ between trial arms and therefore be controlled for in sensitivity analyses.

Eating Rate

Why: understand variations in eating rate between diets – food texture-derived changes from eating rate (slow vs fast) can modulate energy intake (Forde et al., 2026); therefore, any effects between diet arms could contribute to condition differences in energy intake.

How: record meal duration (timestamps (start:finish) derived from Qualtrics software) then calculate eating rate (amount consumed: grams divided by meal duration; min) and energy intake rate (kcal divided by meal duration; min) (Hall et al., 2019; Teo et al., 2021). The rationale for this approach over video recording of eating is because eating rate is a secondary outcome and/or recording eating may modulate behaviour (e.g., feeling of being watched decreasing energy intake).

Data: average eating rate (g/min) and energy intake rate (kcal/min) of meals (breakfast, lunch, dinner) from four-day testing period for each diet.

Liking + Familiarity

Why: understand variations in liking and familiarity between diets – food-based sensorial aspects drive consumption patterns (including what, how much and why) and are considered increasingly relevant (especially texture) in the UPF vs LPF discussion (Forde & de Graaf, 2022).

How: visual analogue scales (VAS; 0-100) on liking [appearance, taste, texture + overall liking; dislike extremely to like extremely], flavour + texture intensity [weak to strong; soft to hard], easiness to consume [very difficult to easy] and familiarity [not to very] (Szczesniak, 2002, Lease et al., 2016; ISO, 2011; ISO 2020; Haydar et al., 2024) post meals. The rationale for post meal relates to minimising disruption of eating for the participant and enables more accurate reporting of eating rate; however, sensory specific satiety and pleasure can decline during a meal compared with first bite, but in this context (laboratory based RCT) post meal is considered more reflective of everyday eating patterns (Rolls et al., 1981; Lasschuijt et al., 2021). Snacks (out-of-the-laboratory consumption) will be rated (as consumed) on the Thursday of each testing period in their food diary. Final attribute selection on relevant sensory characteristics will be based on pilot testing and PPI insights (Appendices, Figure A2-A4).

Data: average liking and familiarity post meals (breakfast, lunch, dinner, snacks) for each diet.

Food Cravings

Why: understand variations in food cravings between diets, as UPFs have been proposed to be craved and linked to self-reported 'food addiction' (LaFata et al., 2024).

How: Food Cravings Questionnaire-State (FCQ-S) measures short-term food craving changes (15-item; five-point scale: strongly disagree to strongly agree) (Cepeda-Benito et al., 2000). This will be completed at the end of each testing period on Thursdays post dinner and will be adapted to reflect the past four-days (Appendices, Table A1).

Data: food craving changes post four-day testing period for each diet (higher scores represent more intense food cravings).

Well-Being

Why: understand variations in well-being between diets – UPF consumption has been proposed to affect mental well-being (Lane et al., 2024).

How: World Health Organisation Well-Being Index (WHO-5) measures subjective well-being (five-item; six-point scale: 'no time' to 'all of the time') (Topp et al., 2015; WHO, 2024). This will be completed at the end of each testing period on Thursdays post dinner and will be adapted to reflect the past four-days (Appendices, Table A2).

Data: well-being changes post four-day testing period for each diet (higher scores indicate better mental well-being).

Gut Health

Why: understand variations in gut health between diets – UPF consumption has been proposed to potentially impact digestion (Whelan et al., 2024).

How: Digestion-associated Quality-of-Life Questionnaire (DQLQ) (9-item; seven-point scale: never to always) (Beke et al., 2022). This will be completed at the end of each testing period on Thursdays post dinner and will be adapted to reflect the past four days (Appendices, Table A3).

Data: gut health changes post four-day testing period for each diet (higher score denotes worse digestion-associated quality-of-life).

Sleep

Why: understand variations in sleep between diets – higher UPF intake has been associated with sleep-related outcomes (such as poor quality, changes in duration) (Delpino et al., 2023).

How: Athen Insomnia Scale (AIS-5) measures difficulty with sleep quantity and quality (five-item; four-point scale: anchors vary by item) (Soldatos et al., 2000). This will be completed at the end of each testing period on Thursdays post dinner and will be adapted to reflect the past four-days (Appendices, Table A4).

Data: sleep changes post four-day testing period for each diet (higher score denotes greater severity of insomnia symptoms).

Physical Activity

Why: monitor physical activity levels between diets – participants will be asked to maintain their typical physical activity levels (Lichtenstein et al., 2021).

How: wear an activity monitor (Fitbit) during each diet period (Monday to Thursday) to measure moderate-vigorous physical activity (MVPA). In addition, discretionary leisure-time physical activity will be captured via the International Physical Activity Questionnaire (IPAQ; part four – adapted to reflect four-day testing period) using the following estimation: MET (min) = physical activity (min) x MET level (walking: 3.3, moderate intensity: 4.0 or vigorous intensity: 8.0) x four days (Craig et al., 2003; Lee et al., 2011). This dual approach has been used in a previous similar RCT (Haynes et al., 2020).

Data: variations in physical activity expenditure from four-day testing period (Monday AM to Friday PM) for each diet.

Body Composition

Why: understand variations in body weight between diets – UPF consumption compared with LPF can lead to weight gain (e.g., Hall et al., 2019; Hamano et al., 2024; Dicken et al., 2025, etc.).

How: measure height (Seca, Stadiometer; nearest 0.5cm) and body weight[12] (Tanita; nearest 0.1kg) in duplicate for screening purposes and enabling BMI characterisation. Body weight will also be recorded (after void to account for diurnal variation) for each testing period (every Monday morning (pre-breakfast; fasted on arrival) and Thursday evening (post dinner after questionnaire metrics)). Participants will be weighed in line with best practice adhering to the Diet, Anthropometry and Physical Activity measurement toolkit: (1) monthly scale calibration and same location in the Eating Behaviour Laboratory on hard/even surface; (2) remove shoes (bare feet), outer clothing (e.g., jackets, sweaters, heavy jewellery, etc.) and empty pockets; and (3) participants will stand in the centre, remain still, arms hanging loosely and head facing forwards (DAPA, 2026).

Data: body weight changes (pre-post; Monday AM to Thursday PM) from four-day testing period for each diet.

TARGET SAMPLE SIZE CALCULATION

The power calculations were performed G*Power (version 3.1.9.6, Heinrich-Heine Universität-Düsseldorf, Germany) (Faul et al., 2007; Lakens and Caldwell, 2025) and confirmed in in R (version 4.5.3) based on testing a main effect by ANOVA repeated measures

[12] including body fat percentage/mass, fat-free mass and today body water for descriptive purposes.

then follow-up with t-test using key assumptions: (1) primary outcome (energy intake); (2) previous RCTs (UPF vs LPF): (i) mean difference: 661 ± 845 kcal and (ii) effect size: 0.78 (large) (Hall et al., 2019; Hamano et al., 2024); and (3) detect a difference in energy density at 0.50kcal/g between diets (UPF vs unmatched LPF) (Robinson et al., 2022). A smaller effect size is also feasible given differences in diets between the present trial and previous trials (e.g., d= 0.78 attenuated by 25% = 0.59).

In G*Power, accounting for the study design (3 groups, 4 repeated measurements [daily energy intake], repeated measures) and paramters of alpha error probability = 0.05; power = 0.80, correlation among repeated measures convservatively estimated at r = 0.5, to detect the average effect size of Hall and Hamano of d = 0.78 (f = 0.39), a minimum N=12 would be required. To account for attenuation of effect size by 25% (see above), a minimum N=18 would be required. We also used the 'superpower' R package and 'ANOVA_power' function to explore power provided by larger sample sizes when adjusting underlying assumptions of power calculation parameters.

Based on the above, we will adopt an interim analysis approach, aiming initially to recruit N=18. At interim (see section below), using a pre-specified approach, we will determine whether additional data collection (i.e., up to maximum N=24 or 30) would increase evidential certainty.

PROCEDURE

STEP ONE - RECRUITMENT: participants will be recruited utilising various approaches (as noted above) and...

- interested participants will respond to study advert by getting in touch with the research team using either email or phone.
- participant information sheet and initial screening questionnaire (including Qualtrics link) will be shared via email.
- discuss next steps with participants based on responses (eligible or exclude).

STEP TWO – SCREENING + CONSENT: eligible participants will be invited to attend an in-person screening session (Eleanor Rathbone Building, University of Liverpool) and complete the following tasks:

- review participation information sheet.
- explain study nature in more detail and opportunity to ask additional questions.
- provide written consent.
- confirm eligibility: (i) measure height and weight then calculate BMI (weight [kg] divided by height [m] squared); (ii) complete remaining screening questionnaires (including Medical History, food allergies list and record basic demographics); (iii) verbally check exclusion criteria (including list of test meals); and (iv) willingness to adhere to study requirements.
- conduct 24-hr dietary recall (1) using Intake24 to understand habitual intake.
- willing to answer questions (self-report) on menstrual cycle if appropriate (female; assigned at birth)

Participants happy to take part will then be asked communication preferences, discuss compliance means (e.g., FitBit, study foods, pre-approved fluids list, food diary, etc.) and organise study visits.

STEP THREE – RANDOMISE + TIMINGS: participants will be randomised to a pre-defined block-design sequence (in advance) and scheduled to attend three four-day (Monday to Thursday) testing periods (UPF, unmatched LPF and matched LPF) with at least one-week washout period. The meal timing is based on providing participants with flexibility whilst at the same time balancing feasibility and ensuring suitable gaps (at least four hours; individual level) between eating occasions approximate timings include: (i) Breakfast: 07:30-09:00; (ii) Lunch: 12:00-14:00; and (iii) Dinner: 17:00-19:00. All main meals will be consumed in the laboratory. Food boxes (snacks + list of pre-approved fluids) and a study diary will be provided

to record intake (including time of consumption, return packaging and record leftovers) out-of-the-laboratory.

STEP FOUR – PRE-VISIT: a reminder email [or preferred format] will be sent the Friday before testing period one including a link to complete a 24-hr dietary recall (2) using Intake24 the next day before bed (Saturday or Sunday) to understand habitual intake.

STEP FIVE – TEST MEALS + METRICS [DIET ONE]: participants will consume main meals in the laboratory in accordance with diet, meal and block sequence. Participants will be provided with all foods for each four-day testing period and asked to refrain from any non-study foods. Various day and meal specific metrics will be recorded as follows:

- **Mondays:** confirm no changes since screening, record body weight in duplicate (pre-breakfast), provide FitBit device and food box/diary for the day.
- **Tuesdays to Thursday:** return previous days food box/diary, compliance check (e.g., non-study foods, FitBit, alcohol, etc.) and provide food box/diary for the day.
- **Thursdays:** snacks will be rated once per testing period (based on ones consumed) in their food diary for liking + familiarity. Record body weight in duplicate post dinner and complete questionnaires (food cravings, well-being, gut-health, sleep).
- **Fridays:** return FitBit device and food box/diary as well as complete physical activity questionnaire.
- **Breakfast:** approximately 30-min between 07:30-09:00 – present allocated meal (ad libitum) and water (500mL) with (i) eating rate recorded using timestamps; (ii) pre-meal appetite (hunger, fullness, thirst); and (iii) post-meal appetite (hunger, fullness, thirst), liking + familiarity.
- **Lunch:** approximately 30-min between 12:00-14:00 – present allocated meal (ad libitum) and water (500mL) with (i) eating rate recorded using timestamps; (ii) pre-meal appetite (hunger, fullness, thirst); and (iii) post-meal appetite (hunger, fullness, thirst), liking + familiarity.
- **Dinner:** approximately 30-min between 17:00-19:00 – present allocated meal (ad libitum) and water (500mL) with (i) eating rate recorded using timestamps; (ii) pre-meal appetite (hunger, fullness, thirst); and (iii) post-meal appetite (hunger, fullness, thirst), liking + familiarity.

STEP SIX – WASHOUT ONE: participants will be asked to follow their normal diet and lifestyle patterns. A reminder email [or preferred format] will be sent the Friday before testing period two.

STEP SEVEN – TEST MEALS + METRICS [DIET TWO + THREE]: repeat same procedures for diet two (STEP FIVE + SIX) and three (STEP FIVE).

STEP EIGHT – DEBRIEF: a debrief will conducted after the final data collection where participants will be asked to: (i) guess the true study aim (impact of food processing or nutritional composition on energy intake) via an open-ended question "*what do you think the aim of this study was*?"; and (ii) awareness of diet differences as a manipulator check by answering an open-ended question "*please can you describe any differences between the presented diets by week?*" then complete a ranking task *"please rank diets (by week) in order of perceived level of industrial processing"* (1 = less processed and 3 = most processed). Data (open-ended responses) will be reviewed by two independent coders and conflicts will be resolved via a third coder.

STEP NINE – REIMBURSEMENT: participants will be reimbursed £300 (upon study completion of three four-day testing periods and relevant tasks) in the form of bank transfer. In addition, a bonus (voucher) payment (£10 x2) will be provided to participants at the drop-off sessions (post testing period one and two – this will not be communicated to participants in advance) to help with study retention (Abdelazeem et al., 2022). This approach was perceived as beneficial for participant retention in a previous similar study (Haynes et al., 2020).

STEP TEN – DATA MANAGEMENT: in brief, data collection, storage and processing (including random allocation of participant codes) on password-protected devices (limited to direct research team) adhering to General Data Protection Regulation (GDPR) guidelines and undergoing regular quality checks. The anonymised data files (supporting relevant peer-review publications) will include a README summary and will be uploaded to a suitable online repository so that others can use it for future research purposes.

Overall, participants will need to attend in person on seven occasions [16 days in total]: (1) screening session (including habitual intake); (2) four-day testing periods (x3); and (3) return food box/diary + FitBit device (Friday post four-day testing period and complete physical activity questionnaire) (x3). In addition, complete habitual intake (2) Saturday or Sunday before testing period one remotely (Table 4).

Table 4. Summary of metrics and corresponding timepoints for each four-day testing period.

Metrics[1,2]	Monday	Tuesday	Wednesday	Thursday
Body weight	Pre-breakfast	-	-	Post-dinner
Physical activity	24-hour•	24-hour•	24-hour•	24-hour•
Energy intake	Meals + snacks	Meals + snacks	Meals + snacks	Meals + snacks
Eating rate	Meals	Meals	Meals	Meals
Appetite	Meals	Meals	Meals	Meals
Liking	Meals	Meals	Meals	Meals
Food box/diary	Daily*	Daily*	Daily*	Daily*
Compliance	Meals	Meals	Meals	Meals
Food cravings	-	-	-	Meals
Well-being	-	-	-	Post-dinner
Gut health	-	-	-	Post-dinner
Sleep	-	-	-	Post-dinner

[1]Body mass index (BMI), habitual intake (1) and demographics will be measured at screening; [2]Saturday or Sunday before testing period one habitual intake (24-hour recall) will be recorded; - denotes n/a; meals = breakfast, lunch + dinner; [#]snacks ratings will be completed in food diary on Thursdays of each testing period; *provide food box (+ diary) with snacks, share pre-approved list of fluids and food box/diary will be returned the next morning; •check FitBit daily and return device Friday after four-day testing period and complete physical activity questionnaire.

STATISTICAL ANALYSIS

The data collected in the laboratory (e.g., foods/drink intake, body weight, etc.) will be recorded manually in duplicate (study log) and then inputted into relevant spreadsheet with independent verification on a different day (add column "checked" to confirm). Software-derived data (e.g., liking, appetite, etc.) from Qualtrics will be sense checked for expected counts; histogram (as appropriate) for visual scanning of all continuous data prior to any analyses. Step-by-step documentation (from raw to edited files for analysis; recording see study checklist) will be saved in study folder and cross-checked on a separate occasion before next steps. Statistical analysis will be conducted blinded (and unblinded post final analyses verified by statistician); all outputs will be saved for future reference. The data will be independently checked by two further researchers.

The analysis will be conducted in R adhering to a pre-agreed protocol with significance defined as $p < 0.05$ (primary) and $p < 0.01$ (secondary/additional: 0.05 divided by six sets of outcomes). Descriptive statistics (mean, standard deviation, counts, percentages) will be utilised to report participant characteristics (e.g., sex, age, BMI, ethnicity, education, employment status, habitual intake, etc.).

Primary Analysis

Energy Intake

Data: daily energy intake (kcal/d; calculated from breakfast, lunch, dinner, snacks) and amount consumed (grams; breakfast, lunch, dinner, snacks) from four-day testing period for each diet (UPF, unmatched LPF and matched LPF). For descriptive purposes we will also compare energy intake by individual meal type (breakfast, lunch, dinner, snacks).

Test: repeated measures (within-subject) ANOVA with three diet arms (UPF, unmatched LPF and matched LPF) and four-days (Monday, Tuesday, Wednesday and Thursday) design. If a significant main effect of condition is present, then follow-up t-tests between trial arms will be conducted.

Significance: $p < 0.05$.

Secondary Analysis

Appetite

Data: appetite ratings (hunger, fullness, thirst from breakfast, lunch, dinner) from four-day testing period for each diet (UPF, unmatched LPF and matched LPF).

Test: repeated measures (within-subject) ANOVA with three diet arms (UPF, unmatched LPF and matched LPF) and four-days (Monday, Tuesday, Wednesday and Thursday) design using AUC (calculated for hunger, fullness and thirst). If a significant main effect of condition is present, then follow-up t-tests between trial arms will be conducted.

Significance: $p < 0.01$.

Additional Analysis

Eating Rate

Data: meal eating rate (g/min; breakfast, lunch, dinner) and energy intake rate (kcal/min; breakfast, lunch, dinner) from four-day testing period for each diet (UPF, unmatched LPF and matched LPF).

Test: repeated measures (within-subject) ANOVA with three diet arms (UPF, unmatched LPF and matched LPF) and four-days (Monday, Tuesday, Wednesday and Thursday) design. If a significant main effect of condition is present, then follow-up t-tests between trial arms will be conducted.

Liking + Familiarity

Data: liking and familiarity ratings (breakfast, lunch, dinner, snacks) from four-day testing period for each diet (UPF, unmatched LPF and matched LPF).

Test: repeated measures (within-subject) ANOVA with three diet arms (UPF, unmatched LPF and matched LPF) and four-days (Monday, Tuesday, Wednesday and Thursday) design. If a significant main effect of condition is present, then follow-up t-tests between trial arms will be conducted.

Food Cravings + Well-Being + Gut Health + Sleep

Data: food cravings, well-being, gut health and sleep from four-day testing period for each diet (UPF, unmatched LPF and matched LPF).

Test: one-way repeated measures (within-subject) ANOVA with three diet arms (UPF, unmatched LPF and matched LPF). If a significant main effect is present, then follow-up t-tests between trial arms will be conducted.

Physical Activity

Data: physical activity expenditure from four-day testing for each diet (individual-level; UPF, unmatched LPF and matched LPF).

Test: one-way repeated measures (within-subject) ANOVA with three diet arms (UPF, unmatched LPF and matched LPF). If a significant main effect is present, then follow-up t-tests between trial arms will be conducted.

Body Composition

Data: body weight (kg) from four-day testing for each diet (individual-level; UPF, unmatched LPF and matched LPF).

Test: repeated measures (within-subject) ANOVA with three diet arms (UPF, unmatched LPF and matched LPF) and pre-post testing period (Monday AM and Thursday PM) design. If a significant main effect is present, then follow-up t-tests between trial arms will be conducted.

Exploratory Analysis

Relationship Between Participant-Level Energy Intake + Body Weight Change

Data: body weight (kg) (pre-post) vs average energy intake (kcal/d) for each diet (individual-level; UPF, unmatched LPF and matched LPF).

Test: multi-level modelling by using (i) change in body weight (pre vs post per diet); and (ii) person-mean centred energy intake by subtracting "mean energy intake across three diets" (UPF, unmatched LPF and matched LPF) from "energy intake within each diet" to isolate changes in energy intake across arms. This will be conducted using the 'lme4' package in R, with a random intercept of participant.

Missing Data

The primary outcome (energy intake) is generally not expected to have any missing data as we will only include participants that complete all three testing periods. However, if there is a small amount of missing data (e.g., missing record for snack box intake on one day, this will then be imputed using the 'mice' package in R (van Ginkel and Kroonenberg, 2014). This will use five imputations with predictive mean matching, and include all relevant data in the imputation. In addition, we will consider using a multi-level modelling approach if we identify significant missing data (e.g., >20%) to more appropriately address this.

Data Exclusion

Data will be excluded from analyses if non-compliance with study protocol (e.g., non-study foods exceeding 350kcal/d; Forde et al. (2026)) or if considered implausible (24-hr recall) (female: 500-3500 kcal/d and male: 800-4000 kcal/d; Willett, 2013) – this will be imputed (as described above).

Sensitivity Analysis

To understand if the results are the same based on excluding: (i) aim guessers (impact of food processing or nutritional composition on energy intake); (ii) manipulation check (identified perceived differences in processing between diets and/or correct order from ranking task); (iii) outliers (if outside threshold: 2.5 median absolute deviation from group mean) (Leys et al 2013); (iv) influential cases (data points above 1.0 based on Cook's distance) (Stevens, 1984); and (v) we will also examine results when any energy intake from non-study foods are included to calculate daily energy intake. For (i) to (v); any deviations in results from the main analyses will be reported. In addition, if we find any evidence of condition differences in the secondary and/or additional analyses then we will examine if results remain the same when they are controlled for (e.g., inclusion as covariates). The primary outcome will be reviewed for diet sequence effects by using a six-level (ABC, ACB, BAC, BCA, CAB, CBA) between-

subjects factor to understand if patterns of results are influenced by presentation order. Data will also be visually evaluated (due to lack of power to detect an effect) to cross-check differences (energy intake vs diet sequence) from main analyses.

Interim Analysis

Interim analysis approaches guide recruitment targets by balancing pre-study uncertainty over expected effect sizes and research waste by analysing the primary outcome at a pre-defined interim timepoint (in this case when N = 18 participants have completed all three conditions) (Lakens, 2014; Ciolino et al., 2023). At interim, we will use Bayes Factors to determine if there is conclusive evidence based on conventional cut-offs to inform if additional data collection would be valuable (e.g., full sample size of up to n = 30) (Rounder et al., 2012; Dienes, 2014; Dienes, 2016).

a) UPF vs. unmatched LPF diet comparison: For informed priors, based on the difference in energy density of the diets in the present study and accounting for a small degree of dietary compensation, a ~480kcal mean difference between the two conditions could be expected and an SD of the difference of ~300kcals, somewhat narrower than previous estimates (Hall et al, 2019) but accounting for the different diets offered. As such our priors will be = 480 SD = 300 with a normal distribution for the alternative hypothesis, and 0 with SD = 100 for the null. Bayes Factors (BF^{10}) will be computed using the 'brms' package, with marginal likelihoods estimated via 'bridgesampling'. We will use a stopping rule of $BF^{10} > 10$ to indicate strong evidence in favour of the null.

b) UPF vs. matched LPF diet comparison. Based on matching of energy density between diet, for the null model (i.e., no difference), we will specify a normal prior with a mean of 0 kcal and a standard deviation of 100 kcal. This prior suggests the mostly likely effect is a 0-kcal difference, with small effects plausible and larger differences becoming progressively less plausible. As the null model is based on not anticipated difference, as such we will examine the BF01 (evidence in favour of the null hypothesis). The alternative prior will be similar to that above (mean = 480, SD = 300). As above, we will use a stopping rule of $BF^{01} > 10$ to indicate strong evidence in favour of the null. Given the uncertainty around both priors we will also examine default/uninformed priors using 'ttestBF' function.

If there is strong evidence for both a) and b) based on the above cut-offs, we will end data collection and progress to the pre-registered analysis approach (described above).

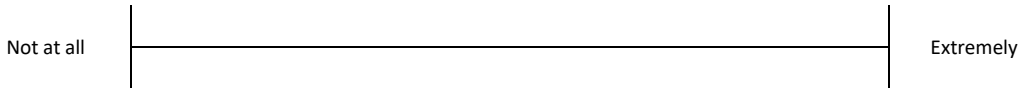
If there is not convincing evidence based on the above, we will conduct inferential statistics to calculate effect sizes for the above comparisons and simulate the effect that increasing sample size to N=24 and N=30 would have on evidential certainty. If these simulations suggest that increasing sample size to N=24 or N=30 would meaningfully increase evidential certainty (e.g., BF>10), we will continue to the desired sample size. If simulations do not suggest that further data collection up to N=30 would meaningfully increase evidential certainty (e.g., minor change in BF), we will end data collection and progress to the pre-registered analysis approach. Bayes factors will also be reported for descriptive purposes for the final analyses.

APPENDICES

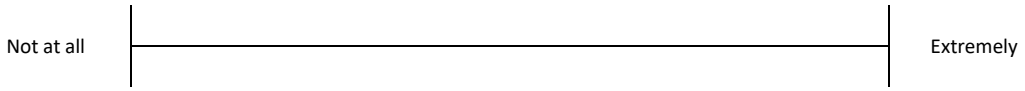
Secondary Outcomes

Appetite

Hunger: How **HUNGRY** do you currently feel?



Fullness: How **FULL** do you currently feel?



Thirst: How **THIRSTY** do you currently feel?

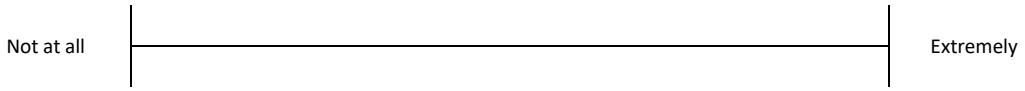
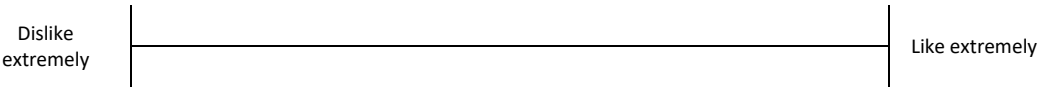


Figure A1. Appetite ratings (pre-post meal) using visual analogue scales (VAS; 0-100).

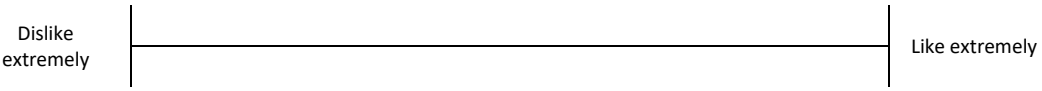
Additional Outcomes

Liking + Familiarity

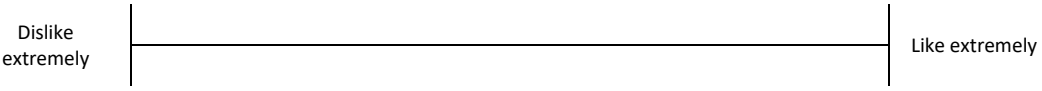
Appearance Liking: How do you rate the **APPEARANCE** of this food/meal?



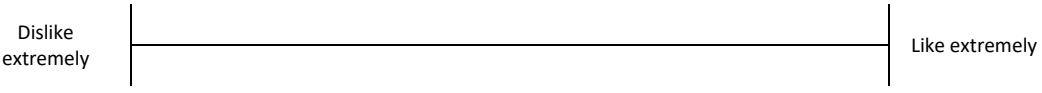
Taste Liking: How do you rate the **TASTE** of this food/meal?



Texture Liking: How do you rate the **TEXTURE** of this food/meal?



Overall Liking: How do you rate the **OVERALL LIKING** of this food/meal?



Familiarity: How **FAMILIAR** is this food/meal to you?

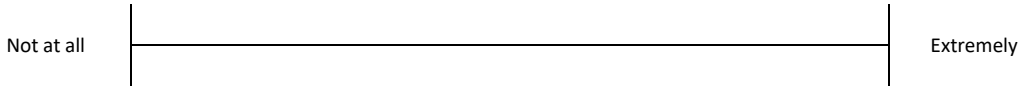
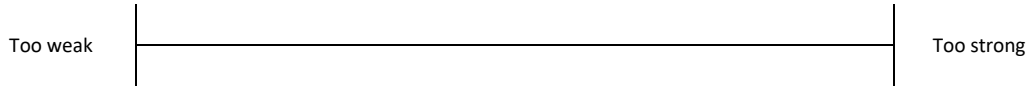


Figure A2. Liking and familiarity ratings (post meal) using visual analogue scales (VAS; 0-100).

Flavour: How do you rate the **FLAVOUR** of this food/meal?



Texture: How do you rate the **TEXTURE** of this food/meal?

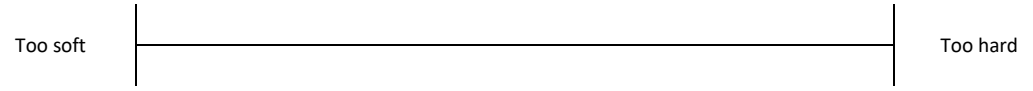


Figure A3. Flavour/texture intensity ratings (post meal) using visual analogue scales (VAS; 0-100).

Easiness to Consume: How do you rate the **EASINESS TO EAT/SWALLOW** of this food/meal?

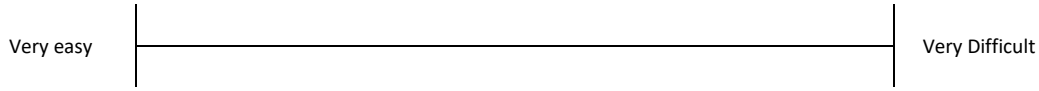


Figure A4. Easiness to consume (post meal) using visual analogue scales (VAS; 0-100).

Food Cravings

Table A1. Food cravings questionnaire (15-item; five-point scale: strongly disagree to strongly agree) (Cepeda-Benito et al., 2000) – "thinking about the past four-days, please answer the following questions by selecting **ONE** response per row".

Question	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I had an intense desire to eat (one or more specific foods)	☐	☐	☐	☐	☐
I had cravings (one or more specific foods)	☐	☐	☐	☐	☐
I had an urge for (one or more specific foods)	☐	☐	☐	☐	☐
Eating [one or more specific foods] would have made things seem just perfect	☐	☐	☐	☐	☐
If I had eaten what I am craving, I am sure my mood would have improved	☐	☐	☐	☐	☐
Eating (one or more specific foods) would have felt wonderful	☐	☐	☐	☐	☐
If I had eaten something, I would not have felt so sluggish and lethargic	☐	☐	☐	☐	☐
Satisfying my craving would have made me feel less grouchy and irritable	☐	☐	☐	☐	☐
I would have felt more alert if I could have satisfied my cravings	☐	☐	☐	☐	☐
If I had (one or more specific foods), I could not have stopped eating	☐	☐	☐	☐	☐
My desire to eat (one or more specific foods) seemed overpowering	☐	☐	☐	☐	☐
I knew I was going to keep on thinking about (one or more specific foods) until I actually had it	☐	☐	☐	☐	☐
I was hungry	☐	☐	☐	☐	☐
If I had eaten right then, my stomach would not have felt as empty	☐	☐	☐	☐	☐
I felt weak because of not eating	☐	☐	☐	☐	☐

Well-Being

Table A2. Well-being questionnaire (5-item; six-point scale; no time to all of the time) (WHO, 2024) – "thinking about the past four-days, please answer the following questions by selecting **ONE** response per row".

Question	No time	Some of the time	< half of the time	> half of the time	Most of the time	All of the time
I have felt cheerful and in good spirits	☐	☐	☐	☐	☐	☐
I have felt calm and relaxed	☐	☐	☐	☐	☐	☐
I have felt active and vigorous	☐	☐	☐	☐	☐	☐
I woke up feeling fresh and rested	☐	☐	☐	☐	☐	☐
My daily life has been filled with things that interest me	☐	☐	☐	☐	☐	☐

Gut Health

Table A3. Gut health questionnaire (9-item; seven-point scale: never to always) (Beke et al., 2022) – "thinking about the past four-days, please answer the following questions by selecting **ONE** response per row".

Question	Never	Rarely	Occasion-ally	Some-times	Frequently	Usually	Always
Physical activities (e.g., running, walking, etc.) were unpleasant or avoided	☐	☐	☐	☐	☐	☐	☐
My usual appetite changed	☐	☐	☐	☐	☐	☐	☐
I was inconvenienced or physically uncomfortable	☐	☐	☐	☐	☐	☐	☐
I avoided certain foods	☐	☐	☐	☐	☐	☐	☐
I was self-conscious or bothered in public or around others	☐	☐	☐	☐	☐	☐	☐
I used the restroom less than I wanted	☐	☐	☐	☐	☐	☐	☐
I was distracted while doing various activities	☐	☐	☐	☐	☐	☐	☐
Social activities (e.g., spending time with friends/family, going out-to-eat, etc.) were unpleasant or avoided	☐	☐	☐	☐	☐	☐	☐
Consuming foods and beverages were less enjoyable	☐	☐	☐	☐	☐	☐	☐

Sleep

Table A4. Sleep questionnaire (5-item; four-point scale: anchors vary by item) (Soldatos et al., 2000) – "thinking about the past four-days, please answer the following questions by selecting **ONE** response per row".

Question	1	2	3	4
Sleep induction (time it takes you to fall asleep after turning off the lights)	No problem	Slightly delayed	Marked delayed	Very delayed
Awakenings during the night	No problem	Minor problem	Considerable problem	Serious problem
Final awakening earlier than desired	Not earlier	A little earlier	Markedly earlier	Much earlier
Total sleep duration	Sufficient	Slightly insufficient	Markedly insufficient	Very insufficient
Overall sleep quality (no matter how long you slept)	Satisfactory	Slightly unsatisfactory	Markedly unsatisfactory	Very unsatisfactory

Physical Activity

Discretionary leisure-time physical activity will be captured via the International Physical Activity Questionnaire (IPAQ; part four – adapted to reflect four-day testing period) using the following estimation: MET (min) = physical activity (min) x MET level (walking: 3.3, moderate intensity: 4.0 or vigorous intensity: 8.0) x four-days (Craig et al., 2003; Lee et al., 2011).

This section is about all the physical activities that you did in the last four-days solely for recreation, sport, exercise or leisure.

1. During the last four-days, on how many days did you walk for at least 10 minutes at a time in your leisure time?
_____ days per week [no walking in leisure time *skip to Q3]*

2. How much time did you usually spend on one of those days walking in your leisure time?
_____ hours per day _____ minutes per day

3. Think about only those physical activities that you did for at least 10-minute at a time. During the last four days, on how many days did you do vigorous physical activities like aerobics, running, fast bicycling, or fast swimming in your leisure time?
_____ days per week [no vigorous activity in leisure time *skip to Q5]*

4. How much time did you usually spend on one of those days doing vigorous physical activities in your leisure time?
_____ hours per day _____ minutes per day

5. Again, think about only those physical activities that you did for at least 10-minute at a time. During the last four-days, on how many days did you do moderate physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis in your leisure time?
_____ days per week

6. How much time did you usually spend on one of those days doing moderate physical activities in your leisure time?
_____ hours per day _____ minutes per day

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