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Teo PS, Lim AJ, Goh AT, R J, Choy JYM, McCrickerd K, Forde CG. Texture-based differences in eating rate influence energy intake for minimally processed and ultra-processed meals. Am J Clin Nutr. 2022 Jul 6;116(1):244-254.

What We Know, Think We Know, or Are Starting to Know

Nutrition science was born in the study of nutrients, with the scientific quest to identify compounds in foods required for life: vitamins and minerals. A nutrient-focused paradigm of research dominated nutrition science for the better part of a century, before voices in the field began to call for a paradigm shift to a food-based research emphasis [we covered this topic in a previous Article].

In 2008, Professor Carlos Monteiro published a paper that suggested that processing, rather than foods or nutrients, explained the adverse health impacts of population diets [(1)]. Monteiro and his research group at the University of São Paolo in Brazil have been strong advocates of the use of the NOVA system of food classification according to degree of processing, which has been formally adopted into Brazilian national dietary guidelines, and embraced by the UN Food and Agriculture Organisation [(2,3)].

Is this a new paradigm shift for nutrition, to one that centres processing as the primary exposure of interest? If it is, there is a long way to go as some major open questions and critiques of the utility of the NOVA system, and specifically the main classification of concern – "ultra-processed foods" – remain [(4,5)].

Ultra-processed foods [UPF] have been defined as "*formulations of ingredients, mostly of exclusive industrial use, typically created by series of industrial techniques and processes*" [(3)]. In colloquial terms, you can't make UPF at home. In many Western industrialised countries, UPF contribute ≥50% of total energy intake [(6,7)], and have been associated with higher risk of obesity and cardio-metabolic disease [(8,9)].

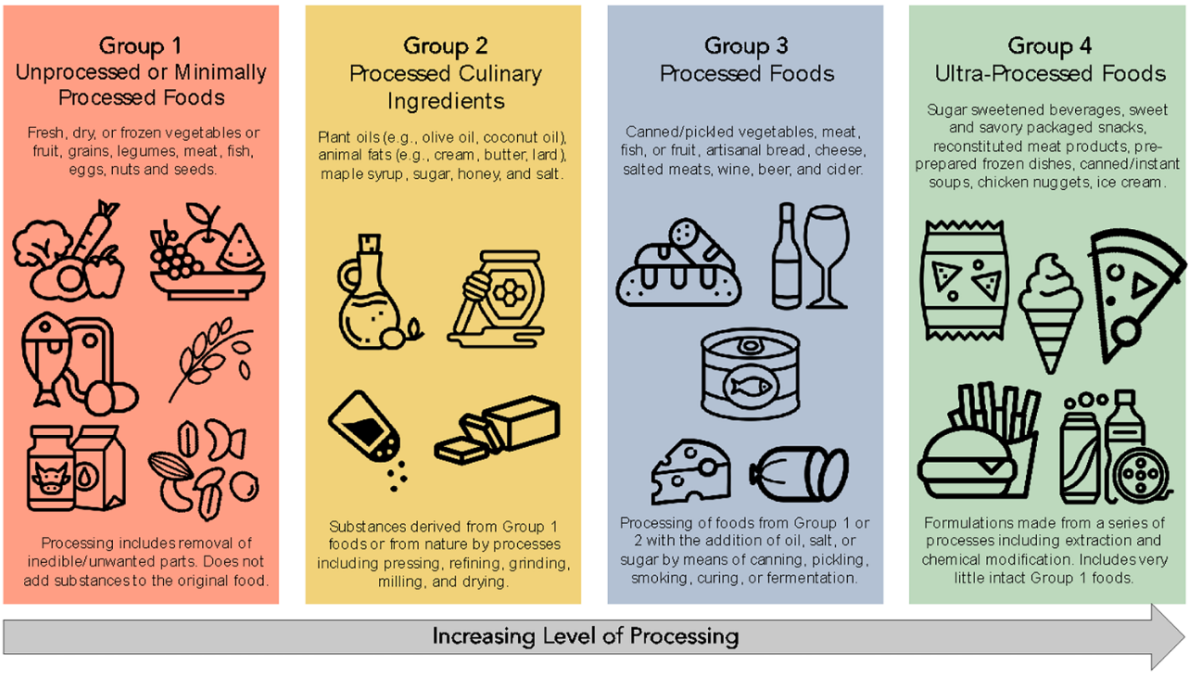


***Figure** from Crimarco et al. [10] illustrating the spectrum of NOVA classifications according to food processing, from Group 1 "unprocessed or minimally processed foods" to "ultra-processed foods". The NOVA classification system makes no further distinctions within a class, i.e., foods are defined by degree of processing and methods only, rather than nutrient or food-based considerations.*

However, the open questions loom large. Is processing *per se* an issue, or do other factors provide more explanatory power as to the effects of UPF? In relation to the potential impacts on energy intake and adiposity, the ease of consumption of UPF has been suggested to explain these relationships [11,12]. In another elegant metabolic ward study by Kevin Hall and his group, consuming a predominantly UPF-based diet resulted in a ~600kcal/d higher energy intake compared to a minimally processed diet [we covered this study in a previous Deepdive].

Using data from this and another trial, Hall *et al*. showed that eating rate significantly predicted energy intake [we have also covered this in a previous Research Lecture]. However, additional characteristics of foods, such as texture, are known to influence both eating rate and energy intake [13–15]. To what extent might texture interact with processing? The present study investigated this question.

The Study

The study was conducted as a 2 x 2 factorial* [see ***Geek Box**, below, for further detail], crossover, randomised trial, in healthy young adults in Singapore. Participants attended a laboratory session where they underwent an *ad libitum* [i.e., eat as much as desired] lunch test meal, comparing food texture and food processing, each with two different types:

- Soft-textured and minimally-processed.
- Soft-textured and ultra-processed.
- Hard-textured and minimally-processed.
- Hard-textured and ultra-processed.

Before arriving to the laboratory, participants were provided with a standardised breakfast and mid-morning snack and instructed to consume these 4 h and 2 h prior to testing [~12pm]. The primary outcomes of the study were eating rate [ER] in grams per minute [g/min], energy intake rate [EIR] in calories per minute [kcal/min], and absolute food intake [grams and calories]. 95% confidence intervals [CI] were reported with these outcomes. Secondary outcomes included sensory ratings of meals, subjective appetite, and food intake subsequent to the test meal.

*Geek Box: 2 x 2 Factorial Design

A 2 x 2 factorial design is a specific trial design which tests two interventions in the one study sample. In a 2 x 2 design, there are two independent variables, and a dependent variable. The 'factor' is the independent variable. Each factor may have different levels. Therefore, in a "2 x 2" design, there are two independent variables [factors] and two levels of each factor. In this study, we have two factors: texture and processing. Within each factor, we have two levels: soft and hard texture, and minimally and ultra-processed. There are a number of results you can get from this type of design, including main effects and/or interaction effects. The 'main effect' is an outcome related to the levels of the factor. In the example of this study, there could be a main effect of food texture if texture had an effect at each level of processing. There could also be a main effect of processing if we found a difference between levels of processing that was independent of texture. You could also have an 'interaction effect', e.g., it could be that the combination of the texture and processing significantly affects outcomes. The present study also utilised a cross-over design, meaning that each subject served as their own control and consumed each of the four test meals. Cross-over designs are useful for nutrition interventions, given that there may be distinct inter-individual differences in metabolism and responses to a particular exposure [either diet or supplement]. Factorial designs are helpful trial designs which allow for different independent variables [the factors] to be included in a single study, so they are an efficient way of doing research. They also allow for interaction effects to be examined, which is important in determining whether differences in treatment may be explained by variations between the factors and levels examined.

Results: 50 participants completed the study, *n* = 24 men and *n* = 26 women. Average BMI was 22.2kg/m^2 in men and 20.5kg/m^2 in women.

***Effects of Meal Characteristics on Eating Rate and Energy Intake Rate*:** Food texture was associated with a significantly greater ER, independently of food processing. ER in grams/minute was 52.3g/min [95% CI, 47.6 to 57.0g/min] for the soft/ultra-processed meal and 45.9g/min [95% CI, 42.6 to 49.3g/min] for the soft/minimally-processed meal, compared to 33.4g/min [95% CI, 30.7 to 36.2g/min] for the hard/ultra-processed meal and 30.3g/min [95% CI, 27.6 to 33.0g/min] for the hard/minimally processed meal.

Both texture and processing were independently associated with EIR in calories/minute. EIR was 66.6kcal/min [95% CI, 60.7 to 72.6kcal/min] in the soft/ultra-processed meal and 53.5kcal/min [95% CI, 49.5 to 57.4kcal/min] in the soft/minimally processed meal, compared to 43.0kcal/min [95% CI, 39.5 to 46.6kcal/min] in the hard/ultra-processed meal and 29.7kcal/min [95% CI, 26.8 to 32.7kcal/min] in the hard/minimally-processed meal.

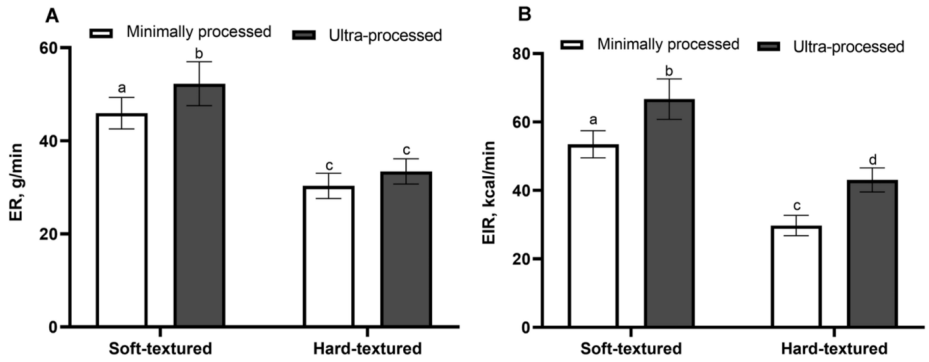


***Figure** from the paper illustrating [**left**] eating rate [ER in g/min] and energy intake rate [EIR in kcal/min]. The independent effects of texture are evident in both graphs, but particularly for ER where there is little difference in ER from hard-textured foods irrespective of processing level. Conversely, for EIR the overall rate was ~24% higher for ultra-processed foods across both levels of texture.*

***Effects of Meal Characteristics on Amount of Food and Energy Consumed*:** The amount of food showed an independent effect of food texture, but not processing. The soft-textured meal resulted in 621.2g [95% CI, 575.7 to 666.7g] total food consumed compared to 482.1g [95% CI, 447.0 to 517.3g] from the hard-textured meal.

Both texture and processing were independently associated with ad libitum energy consumed. The soft-textured meal resulted in 756.5kcal [95% CI, 699.4 to 813.6kcal] consumed, compared to 555.6kcal [95% CI, 510.0 to 601.2kcal] consumed from the hard-textured meal.

The soft/ultra-processed meal resulted in ~300kcal greater energy consumed compared to the hard/minimally-processed meal. Energy consumed was greater from ultra-processed meals in both soft and hard-textured meals, albeit the differences with the soft-textured meals <100kcal.

***Secondary Outcomes*:** There were no significant differences in subjective appetite measures, and sensory factors such as meal pleasantness did not significantly influence the outcomes. Despite significant differences in energy intakes at the lunch test meal, there were no significant differences in subsequent energy intake, i.e., there was no compensatory changes in energy intake later in the day.

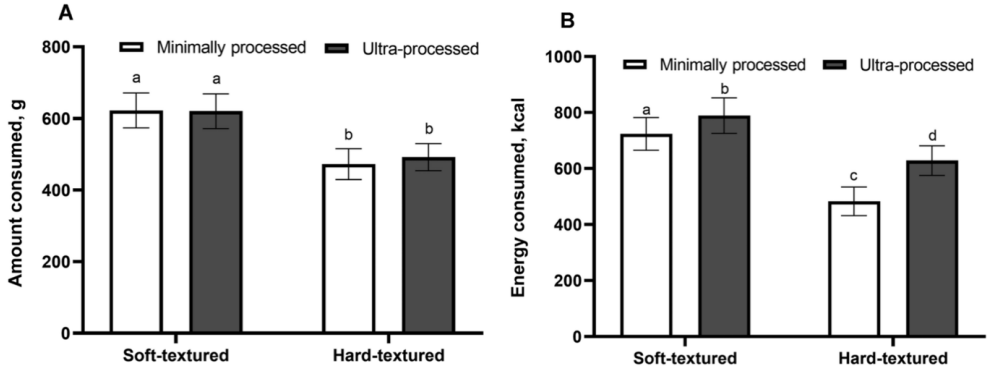


***Figure** from the paper illustrating [**left**] amount of food consumed [in grams] and actual energy consumed [in kcal]. The independent effects of texture are again evident in both graphs, however, what is striking is that in the amount of food consumed was nearly identical on a gram-for-gram basis in both ultra-processed and minimally-processed meals, differing only by food texture.*

The Critical Breakdown

Pros: The study was the first to test the independent and interactive effects of food texture and processing. The aims and hypothesis of the study were clearly stated. The trial was preregistered and there are no apparent deviations from protocol. The study had a strong design [discussed further under *Key Characteristic*, below], and high internal validity with the level of control in a laboratory setting. All meals were matched for macronutrient contents. The study sample was balanced for sex. A standardised breakfast and snack were provided prior to testing to try and counterbalance hunger and appetite of participants before the test meal, which appears to have been achieved as pre-lunch ratings were similar. There was no missing data for the the statistical analysis, and the analysis was robust.

Cons: The sample was young, lean, and healthy, and the findings may not be generalisable as the effects of the food characteristics tested in this study in other population groups. While the study appears to have been adequately powered in its sample size, it is nevertheless a small sample. The study was also confined to acute effects, with primary outcomes only assessed in response to a single meal, and self-reported energy intakes assessed subsequent to that meal on a single day. Thus, caution is required against over-extrapolating short-term proposed mechanisms to long-term outcomes. While the test meals were matched for macronutrients, the energy density and total weight of food between the meals differed, with greater energy density in the ultra-processed compared to minimally-processed meals, in both food texture levels.

Key Characteristic

The 2 x 2 design of the present study [see the ***Geek Box**, above, for further detail] provided an opportunity to test the independent and/or interactive effects of texture and processing, respectively. This is crucial in the context of the debate over the utility of the NOVA classification system, as an open question remains over whether processing *per se* explains effects of UPF on energy intake, or whether other characteristics of the foods may be more explanatory.

And the design of the present study allowed for the independent effects of food texture to be demonstrated, which was largely more explanatory than food processing for most primary outcomes. For example, food texture explained differences in ER, rather than processing, with soft-textured foods resulting in ~35% greater ER compared to hard-textured foods.

The 2 x 2 design also elucidated the independent effects both of texture and processing on EIR, but with no significant interaction effect, i.e., soft-textured foods resulted in higher EIR compared to hard-textured foods at both levels of food processing, and ultra-processed foods resulted in higher EIR compared to minimally processed foods at both levels of food texture.

Thus, overall EIR was 24% higher during ultra-processed compared to minimally-processed meals, across both levels of food texture, and 60% higher during soft compared to hard-textured meals, across both levels of food processing, again indicating that texture exerted a much greater magnitude of effect compared to processing.

And what of actual amount of food and energy intake? Let's discuss this in the next section...

Interesting Finding

In seeking to tease apart the effects of processing from other characteristics of foods, the most interesting findings from the present study are those for amount of food eaten [in grams] and energy consumed [in kcal]. Both of these findings need to be considered together to properly interpret their importance. Refer to the second figure in the results, above, as needed for this section.

The first striking finding is that the amount of food consumed on a gram-per-gram basis was practically identical between minimally and ultra-processed foods; the only significant difference was for food texture, with a 22% lower amount eaten from hard compared to soft-textured foods.

A similar pattern was also demonstrated for energy intake, with hard-textured meals of both minimally and ultra-processed foods resulting in a 26% overall lower energy intake compared to soft-textured meals. However, energy consumed was higher from ultra-processed foods within both soft and hard-textured meals. Because we know that the amount eaten was practically identical, the higher energy intake is attributable to the greater energy density of the ultra-processed meals.

For example, the magnitude of difference in energy consumed in the soft/minimally-processed and soft/ultra-processed meals was negligible, and the energy density differences were 1.13kcal/g and 1.23kcal/g, respectively. Conversely, the greater apparent differences in energy intake between the hard/minimally-processed and hard/ultra-processed meals reflected the meal energy densities of 1.11kcal/g and 1.55kcal/g, respectively.

When taken with the findings for a greater ER and EIR, these findings suggest that food texture exerts a much greater effect on within-meal eating rate and energy intake, compared with energy density differences from ultra-processed foods.

Relevance

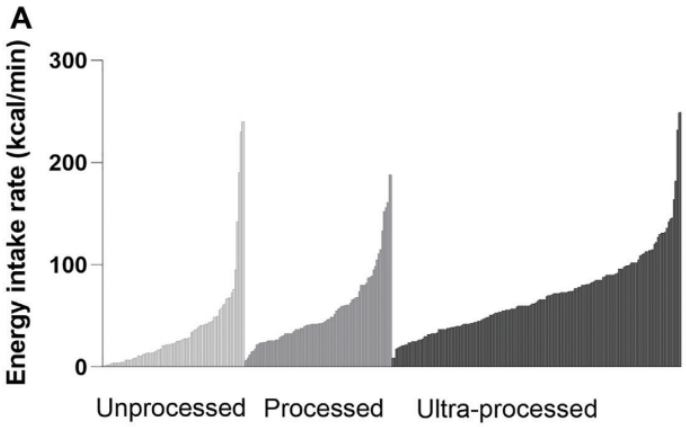
One of the main limitations of the NOVA classification is that it characterises UPF homogenously, i.e., they are defined by processing alone, and this is purported to explain all related health outcomes [4,16]. Think about the definition – "*formulations of ingredients, mostly of exclusive industrial use, typically created by series of industrial techniques and processes*" – this is not a statement that might explain anything of relevance for eating behaviour, postprandial metabolism, or other objective criteria by which we assess the health effects of foods [4].

The present study suggests that it is characteristics of foods that exert greater effects on outcomes such as eating rate and energy intake, beyond what processing classification alone may explain. Several findings are not necessarily new. For example, texture-modified diets are used in clinical dietetics for dysphagia-related conditions [i.e., impaired ability to swallow] [14], and hard-textured foods have previously been shown to decrease *ad libitum* food intake by ~13% compared to soft-textured foods [13].

Eating rate is also a well-established factor, with a meta-analysis of 22 trials showing that a higher eating rate was associated with greater energy intake [17]. And the group

behind the present study previously published a paper suggesting that energy intake rate was associated with 30% higher odds of abdominal adiposity [18].

To what extent do UPF, as defined by the NOVA system, fit this picture? The Hall *et al*. metabolic ward study showed that EIR was 48kcal/min during the UPF-based diet compared to 31kcal/min in the minimally-processed diet [see this previous Deepdive]. A recent pooled analysis of data from five studies showed that while EIR increased across NOVA classifications from lowest with unprocessed to highest with UPF, the variability in EIR from specific foods was substantial [see **figure**, below] [12].



This indicates issues with the homogenous classification system of NOVA, as different foods exert differential effects on these outcomes. And a small pilot study published in July of this year [2023] that compared texture with processing using a similar design as the present study demonstrated that energy intake was 33% greater from soft-textured meals compared to hard-textured, while level of processing had no independent effect [15].

These lines of evidence are quite damaging to the utility of the NOVA classification, by demonstrating that wider characteristics of foods beyond the homogenous classification of processing levels appear to be more explanatory. Nevertheless, they also provide a degree of explanation that if certain UPF are soft-textured and exhibit a high energy density, they may be foods that are easily overconsumed and contribute to excessive energy intakes.

Application to Practice

If the evidence accrues to suggest that the designation of UPF does not independently explain effects of foods in this category, and that different UPF exert different effects relative to their other nutritional characteristics, then the NOVA designation of UPF loses its explanatory power. That open questions remain to be fully resolved, but the overall evidence does appear to be leaning toward suggesting that NOVA may lack specificity and be too opaquely defined to produce effective public health policy.

At the individual level, however, how to think about advising people who are seeing headlines about UPF thrown about in the media? One useful piece of evidence comes from the Dutch “Lifelines” cohort, which conducted an analysis to identify four different clusters of UPF, defined by different characteristics of UPF foods consumed: two patterns were associated with higher odds of type-2 diabetes, one showed no significant

association, and the final cluster was associated with lower risk [19]. This demonstrates the heterogeneity of foods within the NOVA system, and why we should not assume that any food within this classification is inherently “unhealthy”.

So, pragmatically apply prior nutrition knowledge on the characteristics of foods and nutrients we know to be beneficial. Quorn mince is not a BigMac.

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