

Multi-component food-items and eating behaviour

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1 **Multi-component food-items and eating behaviour: what do we know and what**
2 **do we need to know?**
3
4

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28 **Abstract:**

29 Multi-component food-items are single food products that comprise more than one food class,
30 brought together usually via some form of processing. Importantly, individual components of
31 the food-item remain discernible and sensorially distinguishable from each other (e.g.,
32 chocolate chip cookies or ‘choc ice’). Despite a sizable research literature on the formulation
33 of such products, there lacks a concomitant research literature on the effect(s) of multi-
34 component food-items (compared to single component food-items) on eating behaviour.
35 Considerable previous research has investigated the effect of *multiple separate food items* on
36 food intake, portion size selection and palatability. However, studies rarely use test foods that
37 capture the physical or chemical interactions between components that are characteristic of
38 multi-component foods. Nevertheless, previous research and relevant theory allow us to
39 generate hypotheses about how multi-component foods may affect eating behaviour;
40 consideration of food variety and perceived sensory complexity suggest that consumption of
41 multi-component foods are likely to increase perceived palatability of such foods, self-selected
42 portion size and food intake. Moreover, many (but not all) multi-component foods would be
43 considered ultra-processed, which is a driver of food intake in and of itself. One possibility is
44 that food components brought together as part of a multi-component food-item interact to
45 strongly drive eating behaviour. To explore this idea, researchers will need to work across
46 disciplines to address various practical and methodological barriers including the technical
47 preparation of test foods.

48

49

50 **Keywords:** Multi-component food-items; food variety; sensory complexity; ultra-processed
51 foods; portion size; food intake

52

53 **1. Background**

54 Multi-component food-items are those that involve more than one food class being brought
55 together, usually via processing of some kind, in order to make a single food product (Street,
56 1995). Examples offered by Street (1995) include (1) lemon meringue pie, whereby
57 components include pastry, fruit/custard and meringue, and (2) chocolate-chip cookies,
58 whereby the components include pieces of chocolate mixed into a biscuit batter before baking.
59 From a food-science perspective, Street (1995) notes that the compositions of the components
60 within a multi-component food are different, so there is scope for chemical reactions and
61 physical changes that cannot occur if the components are considered alone, and one component
62 can ‘shelter’ another component from the external environment (e.g., ice cream enrobed in
63 chocolate).

64 From a consumer experience perspective, we note that a key feature of these foods is
65 that components remain discernible and sensorially distinguishable from each other within the
66 single food product. Such foods are also likely to be categorised/perceived as a single, usually
67 processed, food -item (e.g., a chocolate chip cookie) rather than a meal comprising separate
68 food items (i.e., a multi-component meal such as ‘fish and chips’). Though we acknowledge
69 that some ambiguities/overlaps between these definitions may exist, especially in cases where
70 a multi-component food-item may be consumed as a whole meal (for example, a cheeseburger
71 or a ‘ready-meal’ lasagne).

72 We also note the overlap between foods that would be considered ‘multi-component’
73 according to the definition above and ‘ultra-processed’ foods. Food processing refers to any
74 change that is made to a food prior to consumption, including basic cooking, smoking and
75 drying for preservation and fermentation (Monteiro, Moubarac, Cannon, Ng, & Popkin, 2013).
76 By contrast, ultra-processing refers to the production of foods via the assembly of ingredients
77 that have been industrially processed, they may have been extracted or refined from whole

78 foods (Moodie et al., 2013). Examples presented by Moodie et al. (2013) include burgers,
79 pizza, cereal bars, nuggets, confectionary and others. We note that many examples of ultra-
80 processed foods are also examples of multi-component foods and represent an overlap between
81 these categories (e.g., cereal bars).

82 Indeed, Street's (1995) definition of multi-component foods refers to the processing
83 that is required to bring components together to create a single food and for some foods this
84 may constitute 'ultra-processing' if components are themselves industrially processed.
85 However, it is important to acknowledge that these terms are not mutually exclusive, and
86 components could be assembled via basic processing of whole foods (e.g., via homecooking).
87 Notably, Meiselman (2017) examined dishes from 19th century menus and examples of multi-
88 component foods can be found (e.g., apple fritters) which would have been created via cooking
89 as a form of processing (with processed flour) but unlikely to meet the definition of ultra-
90 processing. Nevertheless, considering the overlap in foods that could be categorised as both
91 multi-component and ultra-processed, it may be important to consider the place of multi-
92 component foods in the context of ultra-processing of foods and eating behaviour.

93 Despite a considerable scientific literature on the production of multi-component food-
94 items (e.g., Hao, Lu, & Wang, 2017; O'Connor, Favreau-Farhadi, & Barrett, 2018) and the
95 apparent ubiquity of such products within food systems, relatively little is known about how
96 eating behaviour is influenced by the consumption of foods that are 'multi-component' (as
97 opposed to single component). The aim of the current article is to firstly consider multi-
98 component foods in terms of relevant theoretical frameworks of eating behaviour (food variety,
99 sensory complexity and ultra-processed foods). Secondly, we will draw on related research that
100 may offer some insight into the potential effects of multi-component foods on eating behaviour.
101 Drawing on insights from previous research and relevant theoretical frameworks, we will then
102 consider the proposition that multi-component food-items are theoretically interesting because

103 they may uniquely bring together food components that together strongly drive eating
104 behaviour (see Figure 1 for a proposed model). Finally, barriers and opportunities for research
105 on this topic are discussed.

106

107 **2. Relevant theoretical frameworks:**

108 We can consider multi-component foods in the context of eating behaviour in terms of relevant
109 theoretical frameworks. These can be used to generate hypotheses about how multi-component
110 food-items might affect eating behaviour. Here we focus on two frameworks which concern
111 the incorporation of multiple food components into an eating episode (food variety and the
112 ‘variety effect’, and sensory complexity). We also consider multi-component foods in the
113 context of ultra-processed foods, because bringing multiple food classes together will often
114 (but not always) necessitate some sort of processing including ultra-processing.

115

116 **2.1 Food variety and the ‘variety effect’:**

117 The ‘variety effect’ (for review see Raynor & Epstein, 2001; Raynor & Vadiveloo, 2018;
118 Embling et al. 2021) was first demonstrated by Rolls and colleagues (Rolls, Rowe, et al., 1981)
119 who showed that across successive courses of a meal, participants consume more when the
120 foods in each course vary in taste, texture, and colour (e.g., sandwiches filled with egg salad,
121 tomato and pepper, cheese, or ham) compared to when the same food is presented repeatedly
122 (even if it was a favourite food). This effect has also been demonstrated in the context of a
123 meal comprising sandwiches – relative to a single-flavour condition, participants consume a
124 larger meal when a variety of sandwich flavours (e.g, tuna, turkey, roast beef, egg, cheese or
125 ham) is offered. (Spiegel & Stellar, 1990).

126 It is likely that food variety stimulates intake because each time a food with different
127 sensory characteristics is tasted it seems to delay satiation, and when satiation is delayed

128 repeatedly over the course of an eating occasion, more food is eaten overall (Hetherington,
129 Foster, Newman, Anderson, & Norton, 2006). This variety effect is thought to be underpinned
130 by sensory specific satiety (SSS) (Brondel et al., 2009). SSS is the decline in rated pleasantness
131 associated with a food as it is eaten relative to a food that has not been eaten (Rolls, Rolls,
132 Rowe, & Sweeney, 1981). This effect seems to be fundamental to the human eating experience
133 and is likely driven by habituation – a simple and universal form of non-associative learning
134 (Epstein, Temple, Roemmich, & Bouton, 2009); there are demonstrations of SSS being
135 preserved in amnesic patients (Higgs, Williamson, Rotshtein, & Humphreys, 2008) and being
136 resistant to a range of cognitive manipulations (Havermans & Brondel, 2013; Wilkinson &
137 Brunstrom, 2016).

138 One possibility is that multi-component foods represent a form of food variety whereby
139 each sensorially distinct component contributes to the ‘variety’ experienced. Indeed, Raynor
140 and Vadiveloo (2018) outline a form of food variety that could occur “within a food item” and
141 also outline an ‘ingredient-based approach’ to considering food variety whereby each
142 ingredient of a mixed dish contributes to variety (e.g., considering the vegetables contained
143 within chicken soup as single units of variety). However, little research exists using this
144 definition. Considering multi-component foods in terms of the variety effect, one might expect
145 multi-component foods to be associated with greater food intake than a comparator single-
146 component food.

147

148 **2.2 Perceived sensory complexity:**

149 ‘Perceived sensory complexity’ in the context of food and drink, is a concept that refers
150 to the perception of multiple sensations within a single mouthful of a food/ drink as well as
151 across an eating and drinking experience as a whole (Palczak, Blumenthal, & Delarue, 2019;
152 Palczak, Blumenthal, Rogeaux, & Delarue, 2019). The concept of sensory complexity and the

153 accompanying ‘optimal arousal theory’ were first discussed by Dember and Earl (1957) and
154 Berlyne (1967); Optimal arousal theory suggests that hedonic response to a stimulus increases
155 with complexity (e.g., liking for particular patterns that either had few elements constituting
156 low complexity or many elements constituting high complexity) (Berlyne, Borsa, Craw,
157 Gelman, & Mandell, 1965), but that an optimum is reached based on previous experience. After
158 reaching this optimum, hedonic responding declines as complexity increases (an inverted U
159 function). In the context of fragrance/ odour, Jellinek & Koster (1983) developed the related
160 term ‘perceived or psychological complexity’ which emphasises the perception of components
161 (as opposed to components that are present but may not be perceived).

162 In a seminal study, Lévy, MacRae and Koster (2006) tested hypotheses based on
163 ‘optimal arousal theory’ with beverages (an orange soft drink that was manipulated using
164 flavoured oils to create seven drinks with different levels of perceived complexity). They
165 showed that repeated exposure to a drink that had a perceived complexity level that was above
166 an individual’s initial optimum (their most liked drink) shifted their optimum (most liked)
167 upwards (i.e., towards more complex beverages), and less complex products became less liked.
168 By contrast, repeated exposure to a drink that had a perceived complexity level that was below
169 an individual’s initial optimum did not shift that individual’s optimum.

170 From a theoretical perspective, this is explained in terms of a ‘pacer effect’ (Dember &
171 Earl, 1957), where exposure to a stimulus with high perceived complexity shifts an individual’s
172 optimum upwards but exposure to a stimulus with low perceived complexity does not shift an
173 individual’s optimum downwards. Indeed, arousal theory predicts the experience of boredom
174 with stimuli upon repeated exposure but only for stimuli that are below the optimum arousal
175 level. Moreover, one possibility is that these findings are related to the experience of SSS; Lévy
176 and colleagues reported failing to observe SSS for stimuli that had a higher perceived
177 complexity but successfully observed it for stimuli that had a lower perceived complexity.

178 One possibility is that multi-component foods represent a relatively complex category
179 of foods (due to their multiple discernible components providing multiple sensations) and that
180 their repeated consumption shifts individuals' optimum (most liked) upwards, such that multi-
181 component products become preferred over time compared to products that do not contain
182 multiple components. Notably, Koster and Mojet (2016) make a similar suggestion, albeit
183 applied to new food products more generally (rather than to multi-component foods
184 specifically), and suggest that new products that are more complex may enjoy longer term
185 market success compared to less complex products.

186 This proposition remains to be confirmed, with many existing studies focusing on
187 complexity within food and drinks in terms of subtle 'multiple sensations.' For example, wine
188 with a flavour profile including many different 'notes' (Spence & Wang, 2018), or dark solid
189 chocolate bars altered with different flavourings including beet, cinnamon, cardamon and
190 liquorice (Soerensen et al., 2015), may be described as having high perceived flavour
191 complexity but do not constitute a multi-component food when considering a definition that
192 prescribes a need to have discernible components that differ in composition.

193

194 **2.3 Ultra-processed foods:**

195 As mentioned above, ultra-processed foods are those that are produced via industrial
196 processing of ingredients that have been extracted or refined from whole foods (Moodie et al.,
197 2013). Research has shown that an inverse relationship exists between the energy-contribution
198 of ultra-processed foods to the diet and the nutritional quality of that diet (Steele, Popkin,
199 Swinburn, & Monteiro, 2017). Moreover, sales/capita of ultra-processed foods and drinks are
200 positively associated with population-level body mass index trajectories (Vandevijvere et al.,
201 2019) and an influential randomised controlled trial by Hall et al. (2019) showed that inpatients

202 ate significantly more calories on an ultra-processed diet compared to a matched unprocessed
203 diet.

204 A recent paper proposed a model that specifies the properties of ultra-processed foods
205 that are most likely to drive excess intake and in turn weight gain (Rolls, Cunningham, &
206 Diktas, 2020). The model contextualises ultra-processed foods as widely available, often low
207 cost and highly convenient, suggests that ultra-processed foods engender an elevated eating
208 rate, energy density and palatability compared to unprocessed foods and proposes that these
209 factors contribute to the promotion of intake and weight gain. Rolls and colleagues also infer a
210 potential mediating role for satiety with the discussion of studies that have manipulated eating
211 rate and energy density and observed effects on satiety.

212 As previously discussed, there is likely to be some foods that could be considered both
213 ultra-processed and multi-component. Considering evidence that (1) ultra-processing of food
214 is a driver of intake, (2) that multi-component foods may constitute a form of food variety that
215 can also in and of itself increase food intake, and (3) sensory complexity increases liking
216 following repeated consumption; one possibility is that if a food is ultra-processed *and* multi-
217 component, there may be a cooperative effect¹ that leads to greater intake than when a food is
218 either ultra-processed or multi-component alone (see Figure 1).

219

220 **3. Existing research**

221 Whilst there is a paucity of studies considering multi-component food-items and eating
222 behaviour, many studies have tested the effect of a food property (on eating behaviour) that
223 speak in one way or another to our definition of multi-component foods.

224 Such findings generate plausible hypotheses focussed on multi-component food-items and
225 eating behaviour. Studies are organised by the facet of eating behaviour explored; food intake,
226 portion-size selection and liking or enjoyment of food.

227

228 **3.1 Food intake**

229 A number of studies have investigated the effect on food intake of consuming food
230 ‘assortments’ (i.e., food items that are served together but have not been processed to make a
231 single food-item). Hale and Varakin (2016) showed that participants consumed more multi-
232 coloured chocolate candies (Mean candies = 12.5, SD = 17) compared to single-colour
233 chocolate candies (Mean candies = 8.5, SD = 12). Guerrieri et al. (2008) found a similar result
234 between monotonous and varied marshmallows (colour, form, taste and texture), but only in
235 children who were higher in reward-sensitivity. Though, in an earlier study, Rolls et al. (1982)
236 investigated whether increasing colour-only variety would increase intake in a single course
237 compared to a single-colour condition (stimuli were selected to minimise differences in
238 content, taste and smell), and they found no difference in intake of chocolate candies across
239 these conditions. More recently, Vadiveloo et al. (2019) only found an effect of colour or shape
240 variety on intake of fruits and vegetables in specific sub-groups; for example, adults over the
241 age of 36 years old ate more peppers when colour variety was present compared to shape
242 variety, colour and shape variety, and no variety. It should be noted that the studies that
243 described their stimuli in terms of variety in colour, tended not to conduct sensory triangle
244 testing or the updated tetrad testing (likely blindfolded) in order to ensure differences in colour
245 variety were not accompanied by small or minimal differences in taste or other sensory
246 characteristics (for a review of these protocols see (Ishii et al., 2014)).

247 In addition to studies concerning assortments, studies have also investigated the effect
248 on intake of adding spices and condiments to foods (e.g., vegetable intake in children; (Savage,
249 Peterson, Marini, Bordi Jr, & Birch, 2013). In an example in adults, an observational study has
250 investigated food intake and the relationship between the variety of seasonings used when
251 preparing beans and white rice (Vadiveloo, Campos, & Mattei, 2016). Using a population-

252 based case-control approach with 1025 Costa Rican adults, higher seasoning variety (scored
253 from a list of 8 commonly used ingredients) was associated with greater intake of beans and
254 white rice. The addition of seasonings as a way to introduce flavour components is likely to be
255 more subtle than the components that make up a multi-component food and a future study
256 might consider the use of more substantial components (i.e., components that remain
257 discernible and sensorially distinguishable from each other within the single food product).

258 Finally, and by contrast, Levitsky, Iyer and Pacanowski (2012) served participants
259 either a composite meal (stir-fry containing onion, corn, carrots etc...) or a deconstructed
260 version of this meal (e.g., onion, corn, carrots, peas and broccoli served as multiple dishes).
261 They found that participants consumed more (grams) when foods were presented separately
262 rather than as a composite. However, it is perhaps somewhat ambiguous whether the composite
263 meal used in this study constitutes a multi-component food or not and a future study might
264 consider the use of a test food that conforms more closely to the definition of a multi-
265 component food (i.e., a single food comprising discernible components that are physically or
266 chemically interacting with each other).

267 Taken together, whilst results are somewhat mixed, they suggest that when multiple
268 components are presented they are associated with greater intake when compared with a single
269 component. A single study has suggested that when those components are presented 'together'
270 as a composite meal, less is consumed compared to when those components are presented as
271 separate dishes, though future research should seek to replicate this finding.

272 **3.2. Portion size selection**

273 Two studies have used food photography with test foods that could be considered as
274 multi-component foods (Wilkinson, 2013; Bulsing, Gutjar, Zijlstra and Zandstra 2015). Firstly,
275 pilot work ($N = 30$) assessed the portion-size selection of cakes that differed in terms of number
276 of components (low and high) and taste intensity (low and high), but were matched for energy

277 density and pleasantness (Wilkinson, 2013). In this case, cakes with a high number of
278 components were packaged ‘fruit cakes’ which included pieces of fruit within the cake itself
279 and for one of the cakes, topped with a layer of marzipan and icing. For cakes with a low
280 number of components, there were no additional components within the cakes (madeira and
281 golden syrup cakes) and no toppings. As hypothesised, a significantly larger portion size was
282 selected for the cakes with more components ($d = .9$). For now, no attempt has been made to
283 replicate this finding and we note discussion around the risk of pilot studies yielding inflated
284 effect sizes (Kraemer et al., 2006). It is also unclear whether this effect generalises to other
285 foods.

286 In another study, Bulsing, Gutjar, Zijlstra and Zandstra (2015) produced two food
287 photographs of a ‘starter’ course with a low and high number of components in single portion
288 sizes. Participants were asked to estimate their ideal portion sizes of a main course that they
289 would consume after each starter. A significantly smaller portion was chosen in the multi-
290 component condition, though it should be noted that other factors were also manipulated
291 alongside number of components, and so effects cannot be solely attributed to this factor.

292 Another group of studies have explored the effects of assortments on portion size
293 selection (but without a subsequent opportunity to consume the food following selection)
294 (Haws & Redden, 2013; Kinard & Kinard, 2016; Redden & Hoch, 2009). Whilst these findings
295 take different approaches to each other in terms of assessing portion size decisions, they
296 generally converge on the idea that increasing the number of components presented is
297 associated with decisions that would result in a larger portion size being selected. In the most
298 straight-forward demonstration of this, Haws and Redden (2013) found that compared to
299 participants who scored higher in self-control, those who scored lower in self-control chose to
300 consume a greater number of crisps when presented with three types of crisp rather than one
301 type of crisp in a hypothetical task. This result was replicated even when a favourite snack was

302 provided in the ‘one type’ condition. The authors suggested that this effect was likely driven
303 by a greater appreciation for the increased satiety resulting from an increased amount of food
304 (even when varied) that was demonstrated by participants with high self-control compared to
305 low self-control.

306 Taken together, consistent with studies concerned with food intake, the inclusion of
307 multiple components in a food or assortment was generally associated with the selection of
308 larger portions to hypothetically consume, or the evaluation of that food in such a way that
309 would suggest more would be consumed compared to a single food component.

310

311 **3.3 Liking and enjoyment**

312 Several studies have explored the effect of sensory complexity on hedonic responses to
313 foods. Whilst some have shown no effect of complexity on hedonic response with only a subtle
314 manipulation of flavour (e.g., salty crackers with different added flavourings) (Porcherot &
315 Issanchou, 1998; Soerensen, Waehrens, & Byrne, 2015), others have found a limited effect on
316 liking with a more extreme manipulation (e.g., mashed potatoes with pieces of celery and
317 nutmeg added) (Reverdy, Schlich, Köster, Ginon, & Lange, 2010; Weijzen, Zandstra, Alfieri,
318 & de Graaf, 2008). Notably, Weijzen et al. (2008) included test foods that would be considered
319 ‘multi-component’ (e.g., candy bar with chocolate and nuts). Over repeated exposure, test
320 foods that were rated as more complex (candy bar with chocolate and nuts, and wholemeal
321 biscuit with chocolate) were more resistant to a decline in liking compared to plain chocolate
322 and a tea biscuit.

323 Another approach that has been taken is to keep test foods identical across conditions
324 (thereby controlling for liking, energy density and other potential confounding variables) and
325 manipulate participants’ perception of the number of components (rather than the number of
326 components themselves) (Redden, 2008; Galak, Redden, & Kruger, 2009; Embling et al. 2019).

327 For example, Redden (2008) asked participants to consume an assortment of multicoloured
328 candies that were presented with either flavour specific labels (e.g. ‘cherry’, ‘orange’) or a
329 single general label that minimised perception of differences (e.g. ‘jellybean’). Redden found
330 that participants enjoyed the candies significantly more, and a had a greater desire to continue
331 eating, when the candies were presented with flavour-specific labels.

332

333 **4.0 Future directions for research**

334 An important question, therefore, is why research is scant in the area of multi-component foods
335 and eating behaviour? Despite the apparent ubiquity of multi-component food items, there
336 lacks a formal quantification or scoping of their presence across different diets. An indication
337 of widespread access to such products might motivate further research. Future studies might
338 consider an approach similar to studies which have aimed to quantify the availability of ultra-
339 processed foods (e.g., Luiten et al., 2016).

340 Of course, one must always consider the possibility that an absence of research might
341 be explained by the file drawer problem (failure to publish null results) (Rosenthal, 1979).
342 Following some growth of this literature, a future systematic review and meta-analysis might
343 consider this possibility. An alternative explanation is that studies investigating hypotheses
344 relating to multi-component foods (from an eating behaviour perspective) are simply not being
345 conducted; here we discuss potential directions for future research in this area.

346 Methodological considerations are likely to be a key barrier to research in this context
347 and a crucial area for research development. Within the context of multi-component food-items
348 it is likely to be more challenging to identify test foods (compared to producing an assortment
349 of food-items for example) that facilitate hypothesis-testing in this area (i.e., a food that is
350 available as a multi-component or non-multi-component version). It may be relevant that in
351 studies concerned with other effects on food intake, researchers often design a bespoke test

352 food that is manipulated in terms of a key element and matched in terms of extraneous
353 variables. Examples include matched foods that vary only in terms of energy density (e.g.,
354 Wilkinson & Brunstrom, 2009), flavour and texture (e.g., McCrickerd, Chambers, Brunstrom,
355 & Yeomans, 2012) and palatability (e.g., Yeomans, Lee, Gray, & French, 2001).

356 However, manipulation of multi-component food is likely to present more of a
357 challenge in this regard and it may be particularly challenging to match a multi-component
358 food condition against a ‘no multi-component food’ condition because the addition of
359 sensorially-different components to a test food will often affect the energy density, palatability,
360 and so on. Inter-disciplinary collaboration with food technologists, industry and other
361 professionals involved in food product development is likely to be essential to facilitate the use
362 of test foods that reflect the multi-component food experienced by consumers but also meet
363 the needs of a rigorous experimental protocol.

364 Indeed, a group of studies that have probably come the closest to achieving a valid
365 comparison between test foods that are single component and multi-component, was conducted
366 by a multi-disciplinary team generally including authors from a laboratory of Physics and
367 Physical Chemistry of Foods, a Division of Human Nutrition and Health, a Marketing and
368 Consumer Behavior Group, and a public-private partnership that aims to bring together
369 enterprise, industry and research institutes (Aguayo-Mendoza et al., 2020; Aguayo-Mendoza
370 et al., 2021; Santagiuliana et al., 2018).

371 For example, a recent study involved the addition of bell pepper gel pieces to processed
372 cheese and followed a similar study which added peach gel particles to peach yogurt (Aguayo-
373 Mendoza et al., 2020). The aim of this approach was to create ‘heterogenous’ model foods by
374 using a matrix to which components may be added to or not and to assess effects on oral
375 processing behaviour. In both example studies (Aguayo-Mendoza et al., 2020; Aguayo-
376 Mendoza et al., 2021), the addition of particles increased the number of chews and

377 consumption time, which reduced eating rate. Though the magnitude of effect was dependent
378 on the overall texture of the matrix, with larger effects associated with a softer matrix compared
379 to a harder matrix. While another study has shown that the addition of particles to model soups
380 and gels led to a decrease in liking (Santagiuliana et al., 2018).

381 The heterogenous model foods created by Aguayo-Mendoza and colleagues likely fulfil
382 the definitions of ultra-processed foods and multi-component food-items discussed here.
383 Though future research might consider extending such approaches to achieve greater
384 ecological validity, for example, the inclusion of different flavours of components, indulgent
385 category components/ matrix foods and variations in energy density (carefully matched across
386 single component and multi-component test foods). In addition, the outcomes investigated by
387 these studies did not include intake and portion size selection. More generally, the results of
388 this line of research highlight the nuance required when considering ultra-processed and multi-
389 component foods from a health perspective; here results suggest that the addition of
390 fruit/vegetable-based components to model foods may engender beneficial oral processing
391 behaviours such as slowing eating rate. It may also be that these approaches could be
392 capitalised on to aid rather than undermine consumer health, whether that involves increasing
393 intake of low energy density, nutrient-dense, foods or decreasing intake of high energy density,
394 nutrient-poor foods.

395 Another approach, and distinct question, is to consider a potential ‘dose response’ effect
396 whereby the relationship between eating behaviours and number of components within a multi-
397 component food is explored. From a test-food production perspective, this might be relatively
398 easy, because the inclusion of components in a ‘control’ test food allows for further variation
399 of those components for comparison with a greater number of sensorially distinct components.
400 This approach could be implemented via the incorporation of pre-existing products with ‘built
401 in’ sensory variety (like different coloured and flavoured candies that already tend to be calorie-

402 matched) into a base food, for example, a chocolate brownie with all of one colour/ flavour
403 candy compared to a chocolate brownie with multi-coloured/ flavoured candies.

404 However, the inclusion of bespoke test foods in research may be a barrier to study
405 execution because of costs associated with food production and other practical ramifications.
406 One approach that might allow for such research to be conducted without prohibitive costs is
407 to make use of photograph-based methodologies. The use of photographs of foods to assess
408 portion size selection has previously been used and validated against food intake more
409 generally (Wilkinson et al., 2012) but has also been used to demonstrate the classic variety
410 effect (Wilkinson, Hinton, Fay, Rogers, & Brunstrom, 2013). This involves taking photos of a
411 particular test food in different portion sizes (incrementally increasing from a very small
412 portion size to a very large portion size). By taking this approach test foods only need to be
413 produced for the purpose of creating the set of portion size photographs. The photographs can
414 then be presented to participants in a portion size selection task rather than as a test food. Of
415 course, this approach might not be appropriate if the sensory manipulation of a test food is not
416 visually obvious, although creative solutions might mitigate this problem, for example, cross-
417 sections of foods might allow for ‘hidden’ components to be viewed or the accompaniment of
418 a small taste test portion might allow for subtle taste manipulations to be appreciated without
419 the cost of producing larger portions. Ideally, both portion size selection and actual intake
420 would be assessed, but this approach may allow for preliminary work to be conducted to inform
421 more expensive subsequent research.

422 Finally, in a related highly innovative approach, the effect of within-meal vegetable
423 variety on portion size selection (from vegetables) has been investigated using a buffet of
424 replica foods (Fake Food Buffet) (Bucher, van der Horst, & Siegrist, 2011). This meant that
425 fresh foods were not required for each testing session, removing significant costs and
426 preparation requirements from the study. They found that, compared to presenting participants

427 with the choice of a single vegetable side dish, participants would select larger portions when
428 they could choose from two vegetable side dishes as part of a meal.

429 Alongside foundational work which aims to quantify the basic effect of multi-
430 component foods on outcomes such as intake, researchers might also consider potential
431 moderators of such effects, including the assessment of individual differences. For example,
432 because previous research (reviewed above) has shown that children with high reward
433 sensitivity are especially sensitive to the effects of exposure to monotonous and varied foods
434 (Guerrieri et al., 2008), this trait merits further investigation. Researchers might also consider
435 the effect of perceived healthiness of particular components on overall intake of a multi-
436 component food. For example, the inclusion of a component that is likely perceived as healthy
437 in a multi-component food that might otherwise be considered unhealthy (e.g., carrot pieces
438 included in carrot cake). Previous research has suggested that perceived healthiness can be a
439 driver of food intake (Provencher et al., 2009) but such effects remain unexplored in the context
440 of multi-component foods.

441

442 **5.0 Conclusions**

443 In summary, we argue that the potential for multi-component foods to affect eating
444 behaviour is an important but under-researched topic. This is because, given our discussions
445 around food variety and perceived complexity, and preliminary evidence from the relevant
446 extant literature, it is likely that multi-component foods are a driver of food intake. Moreover,
447 a potential overlap between multi-component foods and ultra-processed foods may compound
448 such effects. From a health perspective, if these effects were capitalised on to increase
449 consumption and liking for low energy density and high micro-nutrient dense foods then this
450 could help prevent under-nutrition. However, if foods with these properties are also high
451 energy density and low micro-nutrient dense then this may drive over-eating and obesity. We

452 suggest that research in this area has been hindered by methodological barriers, in particular,
453 around test food production. It does seem that there are promising approaches to systematically
454 examining the effects of multi-component foods (e.g., further developed versions of
455 heterogenous model foods as used by Aguayo-Mendoza et al. 2021). Researchers conducting
456 studies in this area might consider multi-disciplinary collaborations in order to capitalise on
457 such food technology innovations, as well as methodologies that facilitate a pragmatic way of
458 conducting studies with resource intensive test-foods.

459

460 Footnote:

461 ¹ We acknowledge contemporary commentary on the difficulty of quantifying supra-additive
462 effects (when the whole is more than the sum of its parts), and adopt the suggestion of referring
463 to cooperative effects, defined as a combined effect that is greater than the individual effect of
464 each factor (for review see Geary, 2013).

465

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