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Investigating cognitive biases: Does halo effect from nutrition or health claims drive negative calorie illusion in food combinations?

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Abstract

People in developed countries have access to healthier food options. However, there is also an increasing availability of energy-dense foods. While energy-dense foods play a major role in food accessibility, their prevalence also escalates the obesogenic environment. This paper aims to understand the role of cognitive biases on food consumption from the view of calorie underestimation. Specifically, the study examines how consumers perceive food calorie content and how consumers interpret the claims on food packaging. 525 UK respondents were asked to evaluate five different food combinations. The average calorie estimations for each meal were compared with their actual calorie contents to identify underestimation/overestimation. T-test was conducted, logistic regression model and linear regression model were analyzed. The results show that heuristic is often adopted in food selection. Foods are categorized into vice and virtue according to the different goals they support. The existence of virtue food options (e.g., fruit and vegetable) reduces the perceived calorie content of the meal. Likewise, nutrition and health claims such as low-fat and zero-sugar also decrease the calorie estimation, especially when the labelled food is unhealthy. Considering overeating is a consequence of calorie underestimation, consumers' knowledge of nutritional quality needs to be improved.

Keywords. Nutrition claims, health claims, five-a-day campaign, calories estimation, food combinations, virtue foods

1 Introduction

In principle, healthy nutrition and food security should be complementary, but there are some clashes in practice. For instance, the inexpensive, tasty, and energy-dense food has thrived with the development of food and agriculture technology (Jackson et al., 2020; Lin & Li, 2021). On the one hand, such food plays a major role in providing affordable calorie intake for moderately food insecure population to ensure food accessibility (FAO, 2022). On the other hand, they also boosted the obesogenic modern environment (Jackson et al., 2020). Because these highly processed foods are normally high in sugar, salt and saturated fat but lack essential nutrients. Consumers who mainly count on them as food sources may end up suffering both overweight and undernutrition (FAO, 2022).

Notably, developed countries such as the United States and the UK are also plagued by the prevalence of obesity (Allender & Rayner, 2007; Janssen et al., 2020; Olshansky et al., 2005). While people in these countries technically have more access to other healthier food options, their consumption of ultra-processed food products is also high (Rauber et al., 2020). Several studies that revealed an association between calorie underestimation, excessive calorie consumption and obesity. This conclusion can be found from studies which compared the actual caloric intake with self-reported estimates of intake from participants with low and high BMIs (Lansky & Brownell, 1982; Tooze et al., 2004; Olshansky et al., 2005). However, the studies on calorie illusion focused on its formation, thus, do not sufficiently address current lack of obesity prevention instruments.

Moreover, health-eating messages on food packaging such as nutrition claim, health claim and food campaigns that were envisioned to mitigate such environment in some cases end up aggravating it because they are perceived as a permission for overeating (Cleeren et al., 2016; Wansink & Chandon, 2006). Calorie underestimation arising from consumer's heuristic decision-making strategy might be able to explain the dilemma. To establish effective interventions for obesity prevalence whilst guaranteeing food accessibility, it is critical to understand how consumers perceive the calorie content and how they interpret the claims on food packaging.

Conventionally it is assumed that people would estimate the calorie content of a food combination/a meal according to the sum of each items' calorie content. But current available nutrition information on the pack mostly describes the calorie content per serving instead of the whole meal while food and drinks tend to involve multiple servings. This makes it more complicated to estimate the total calorie content of a meal as consumers typically are not able to estimate their portion size (Chernev & David, 2010). Moreover, Chernev & David (2010) indicated that systematic biases appear when people estimate the calorie content of food combinations. Although Carels et al (2007) claimed that people's calorie underestimation on healthy food items nearly offset their calorie overestimation on unhealthy food items, Chernev and David (2010) argued that consumers commonly underestimate the calorie content of a meal when both these two types of food items are combined in one meal.

There is much to be learnt about the impact of nutrition and health claims on food consumption decisions. Firstly, although the nutrition and health claims have been proved to exaggerate the health benefit of food products, to what extent they could mislead consumers to underestimate the calorie content is not fully explored (Ebneter et al., 2013; Mai & Hoffmann, 2015; Roe et al., 1999; Wansink, 2004). Most studies examining these claims have only focused on fat-related nutrition claims (e.g., low-fat). The nutrition claims about sugar and energy content are not fully investigated in previous studies on how food choices are influenced by nutrition claim, thus, the generalizability are limited (Oostenbach et al., 2019). Second, the generalizability may also be limited by the food category involved in the studies as most of them were snack foods (Oostenbach et al., 2019). Also, the influence of claims was mainly assessed in single food items (Ebneter et al., 2013; Faulkner et al., 2013; Wansink & Chandon, 2006). Third, despite the findings that nutrition and health claims can mislead consumers, previous studies have not drawn particular conclusions on to what extent the consumers are misguided by these claims (Orquin & Scholderer, 2015).

In order to address some of these gaps, this paper extends the research on calorie estimation bias to a more realistic scenario. Also, this paper introduces health claim,

nutrition claim and five-a-day campaign into the design of stimulus to find out their role in categorizing vice and virtue options and calorie estimation. Compared to previous studies that focused on individual food items (Booth, 1987; Carels et al., 2006, 2007; Chernev & David, 2010), this paper estimates the calorie content of a meal that combined both healthy and unhealthy food items. This enables examining possible biased perception of calorie content when consumers try to approximate the calorie content of multiple foods while also averaging their vice and virtue attributes.

2 Methodology

2.1 Data collection

Respondents were 525 people recruited via Prolific. Prolific is an online research platform which provides researchers with access to diverse participants, and they will receive monetary reward for taking part in experiments. Meanwhile, prior to publishing the survey on Prolific, the participants were prescreened to be aged from 18-80 and located in the UK. Selecting the population in the UK is because the UK is one of the countries suffering from obesity issue, and the 5-a-day campaign, whose impact was to be investigated in this study, has been supported by its National Health System (NHS) and functioned in this country for over 20 years (Allender & Rayner, 2007; NHS, 2022). These participants were asked to complete a questionnaire that is implemented through a questionnaire tool (Smart Survey).

2.2 Experiment design

The respondents were asked to provide some of their demographic information including age, gender, weight, and height (for later BMI computation), and diet status. And there were also questions requiring them to assess their guilt about consuming unhealthy food and their knowledge about calorie estimation. We also elicited information about the body weight management. All these individual differences have been revealed to be associated

with consumer's perception of calorie content (Carels et al., 2007; Chernev & David, 2010; Wansink & Chandon, 2006).

Subsequent questions were to check consumer's judgment of calorie content of food and were created mainly based on studies about bias in calorie estimation (Chernev, 2011; Chernev & David, 2010). Additionally, to bridge the knowledge gaps, new stimuli including nutrition claim, health claims and 5-a-day statement were added to find out whether they are able to strengthen the virtue attribute of the meals. And such an effect, if happened, is expected to further lower respondent's perceived calorie content of the meal. Also, as this study aims to discover the calorie estimation in the context of an entire meal instead of single food item, each meal contains two stimuli. The constant one is a burger, which acts as the main course of a meal, and the other is either a snack or a drink that is usually consumed together with the main course. The specific compositions of all five meals in this study are shown in **Table 1**. The division of respondents into individual age groups follow previous studies (e.g. Kügler, 1999; Mostaghim et al., 2017) that segment the population into these age groups to study behaviours, preferences, health outcomes, or any other variable of interest that might change with age.

[Table 1 here]

Respondents were randomly assigned to one of these five meals and viewed the pictorial and verbal description of it (**Table 1**). Then they were asked to estimate the calorie content of the meal in the unit of kcal. In addition, respondents' health perception assessment of the meal was elicited on a 5-point scale (1 unhealthy, 2 slightly healthy, 3 somewhat healthy, 4 moderately healthy, 5 very healthy). Meanwhile, to minimize the variance caused by people's lack of accurate calorie-content knowledge (Burton et al., 2006; Sharpe et al., 2008), a different burger (**Table 1**) was shown to all respondents, and they were told the calorie content of it (300.3 kcal). This burger is designed to act as a reference point to calibrate respondent's calorie estimations (Chernev & David, 2010).

2.3 Analytical technique

Firstly, the average estimated calorie content of each meal was compared to the actual calorie content of it. The actual calorie content of each meal was computed by adding up the calorie contents of two food items involved, and calorie content of food items are based on the nutrition fact panel on the packaging (not visible to the respondents in this experiment). When evaluating the calorie content of a meal, previous studies spotted the "negative calorie illusion" as they found the unhealthy food item combined with a healthy food item were believed to contain less calorie than unhealthy item alone (Chernev, 2011; Chernev & David, 2010). But such calorie underestimation was according to the calorie content of the control group rather than the actual calorie content. And those studies identified calorie estimation based on the actual calorie content only focused on a single food item instead of a meal (Carels et al., 2006; Wansink & Chandon, 2006). Therefore, this comparison is trying to check whether the calorie underestimation happened on single healthy food items can be replicated in the estimation of a meal's calorie content while using its actual calorie content as a baseline.

Secondly, this study introduced nutrition claim (e.g., zero sugar, no added sugar, and 0%fat), health claim (e.g., gut health) and 5-a-day claim as new stimuli and assumed they will further promote the good/bad categorization of a meal. Amongst the five meals, there are two groups of meal intended to evaluate the influence of these new stimuli. Meal 1 and meal 5 have similar food combinations while only meal 1 has the zero-sugar claim. Also, the food combinations of meal 2 and 3 are identical and the only difference is meal 3 has an extra statement to clarify it counts as one of your 5-a-day. Comparing the mean calorie estimations of two similar/same meals that differ mainly in the presence of claims allows to identify whether their exaggeration of health benefit can be reflected on perceived calorie content. In this study, Welch Two Sample t-test was applied to compare the mean calorie estimations between two meals in each group.

Lastly, the mechanism for people to underestimate/overestimate the calorie content of food remains disputable. The pioneer study on averaging bias claimed that people's overall

healthiness perception of the meal determined their inferences of its calorie content (Chernev & David, 2010). However, as discussed earlier, the individual differences and the presence of various claims are also able to manipulate people's judgement of calorie content of food. To ascertain the impact of these factors, they were considered as explanatory variables in the model of calorie estimation.

2.4 Description of the statistical analysis

When respondent's estimated calorie content was higher than the actual calorie content, the respondent overestimated. And when it was lower than the actual one, the meal's calorie content was underestimated. Such binary outcome variable was analyzed using the logit model. All overestimations in the responses were coded as 0 in the dataset and all underestimations were coded as 1. Additionally, the estimated calorie content as a continuous variable was also analyzed using linear regression.

$$\begin{aligned} &Underestimation\ of\ calorie\ content \sim age + gender + BMI \\ &+ calory\_knowledge + weight\_management + guilt \\ &+ food\_combination \\ &+ health\_perception \end{aligned} \quad (1)$$

$$\begin{aligned} Estimated\ calorie\ content \sim\ & age + gender + BMI \\ &+ calory\_knowledge + weight\_management + guilt \\ &+ food\_combination + health\_perception \end{aligned} \quad (2)$$

Equation 1 (binomial logit) and Equation 2 (linear regression) both have the same independent variables. The data was analyzed using R. The value for the scales of each determinant and their meaning are shown in **Table 2**.

[Table 2 here]

3 Result and discussion

3.1 Descriptive analysis

Table 3 has summarized the demographic composition of respondents. Almost two third (61.33%) of respondents were female and it was reported that they would pay more attention to nutrition label and could better identify healthy food than male (Oakes & Slotterback, 2007). Unexpectedly, even most of respondents were female, only less than one third (31.43%) respondents reported they always check the nutrition fact panel on food packaging. As discussed in section 2.2, inaccurate perception of calorie content comes from the adoption of heuristic, which is a mental shortcut to make decision using the least mental effort (Tversky & Kahneman, 1974). Lack of attention to the nutrition fact panel where the specific value of nutrients (e.g., calorie content and fat content) can be found suggests that people tend to not bother to obtain such information. A possible explanation for this might be the enormous food decisions every day and the overwhelming food messages from various sources have made it too hard and time-consuming for consumers to make informed decisions every time they purchase food (National Cancer Institute, 2005; Schwartz & Borra, 1997). This further supported the idea that consumers tend to adopt heuristic notions to simplify the selection of food.

Additionally, 30.86% of respondents reported that they are less likely to check the nutrition fact panel if there is nutrition claim or health claim. This result is consistent with Roe et al. (1999) who found the claims on the front of package reduce the likelihood of checking the nutrition fact panel on the back. This observation may imply that the nutrition and health claims override the nutrition fact panel. Consumers possibly infer from them that food products with these claims are good for their health and are superior versions of the regular products(Andrews et al., 2009; Ebneter et al., 2013; Mai & Hoffmann, 2015). Although such good impressions may make consumers neglect the actual nutrition content of the food products, nutrition and health claims provided a shortcut for them to spot the comparatively healthier food products more easily. Meanwhile, 37.71% of respondents did not pay attention to either the nutrition fact panel or the claims on food package. Therefore,

although messages on food packages such as health and nutrition claims and 5-a-day campaign could influence consumers inference of food products labelled with them, such influence could be limited as a considerate number of consumers might not even notice these messages.

[Table 3 here]

Another finding that stands out from the results reported in **Table 4** is that the long-term self-discipline goal (body weight control) was widely pursued by respondents, but their acts may not be consistent with this goal. Almost all respondents (98.29%) have shown different degrees of awareness of body weight management, and most of them (77.90%) cared more than moderately (score over 5) about their body weight management. Interestingly, according to the standard of WHO (WHO, 2014), about 30.14% of the respondents were overweight (BMI>25), and 24.85% were obese (BMI>30). These results replicated "the dieter's paradox" again (Chernev, 2011). Dieters who concerned about body weight management are believed to be good at recognizing calorie content of food, and this is a key reason for them to avoid overeating (Eckel, 2008). A possible explanation for their accurate calorie estimation might be they highly involved and systematically processed available information which reduced the occurrence of biases (Bettman et al., 1998; Payne, 1976).

However, such good capacity of evaluating calorie content cannot be extrapolated to all dieters. Although most of respondents claimed they are concerned about their body weight management, it was paradoxical that more than 50% of them still have high BMIs. There are several possible explanations for such inconsistency. Firstly, a common reason to gain weight is people do not have sufficient willpower to monitor and control their consumption behavior (Fishbach & Zhang, 2008). Even if dieters are trying to control their weight, they might not have enough self-discipline to sustain a strict diet plan. In addition, consumers, especially those who are on a diet, may mistakenly believe that adding healthy food (e.g., fruit and vegetable salad) can decrease the calorie content of the combined meal. Such underestimation of calorie content may give them false permission

to overeat (Chan et al., 2004). Last but not least, although only about 40% of respondents reported that they do not know the calorie content of food well, the actual proportion is likely to be higher than this as people may not be willing to admit they do not understand something. This assertion is backed by the fact that many of the respondents have high BMI and high BMI is reported to be related to lower accuracy of calorie estimation (Carels et al., 2006).

[Table 4 here]

Moreover, the respondents were asked to assess the calorie content of five meals and the average estimations also exhibited biases of different degrees. Figure 1 depicts the comparison between the mean calorie estimations for each meal and their actual calorie contents. Based on the extent to which the food item aligns with the indulgence/self-control goal, food items are categorized as vice/virtue (Chernev & David, 2010). Consistent with the balancing rule in Chernev and David's (2010) research, the calorie content of the combination including vice and virtue options (meal 3 and 4) was underestimated and the calorie content of the combination including two vice options (meal 1 and 5) was overestimated. However, it is somewhat surprising that the calorie content of meal 2 was overestimated even though it also contained vice and virtue options.

[Figure 1 here]

The data reported in this section appears to support the assumption that consumers are not likely to always involve accurate nutrition information in their judgements. Without the specific value of calorie content, consumers can only use their own knowledge of calorie content of food and their perception of the food's healthiness to evaluate the calorie content. Although such method can save time that could have been spent on checking the nutrition fact panel and subsequent computation, the estimated calorie content is always biased because the food item's intensity of vice/virtue is only their subjective judgement which cannot serve as solid basis to infer an objective quantity, namely calorie content.

A straightforward solution to avoid such bias seems to be encouraging consumers to check the exact calorie content printed on food packages. Once consumers are aware of a specific value, they do not have to estimate. However, as long as time and computational resources remain to constrain consumers, decision making heuristics might still tend to be prioritized over the adoption of nutrition information (Rodríguez-Entrena & Salazar-Ordóñez, 2013). As discussed earlier, consumers may not pay attention to the nutrition information so providing or even highlighting calorie content in nutrition information may only have limited effect in reducing calorie consumption. A further risk of excessively stressing one type of nutrition (e.g., calorie content) could be misleading consumers to overlook the overall nutrition density of the food items(Howlett et al., 2012; VanEpps et al., 2016). For example, some food combinations might feature low in calories, but their nutritional content could also be poor.

3.2 T-test analysis

Respondents were randomly assigned to evaluate one of the five meals, and each meal had 113, 105, 102, 103, 100 observations. To find out the function of claims and 5-a-day label, there were two pairs of meals including similar or the same food combinations. Meal 2 and meal 3 included a burger and three celery sticks while only the celery in meal 3 was attached with 5-a-day label and statement. Similarly, meal 1 included a burger and a zero-sugar cola while meal 5 included a burger and a regular cola.

As summarized in Table 5, the mean calorie estimation for the meal containing zero-sugar cola (451.48 kcal) was significantly lower than the mean calorie estimation for the meal containing regular cola (673.49 kcal) ($t=4.814$, p-value<0.001). Further, as presented in Figure 1, the actual reduction in the calorie content (138 kcal) from choosing zero-sugar cola was less than the estimated reduction in calorie content (222.01 kcal). This finding further agrees the health benefits of nutrition claims such as zero-sugar and low-fat could be falsely amplified (Wansink, 2004). There are two likely causes for the different calorie estimation between meal 1 and meal 5. One is that zero-sugar cola has less calories than regular cola, and hence the meal with the former should contain less calories. The other

explanation could be that the "halo effect" of zero-sugar nutrition claim enhanced the meal's intensity of virtue and lead to lower calorie inference.

By contrast, there is not a significant difference between the calorie estimations for meal 2 and meal 3 ($t=1.653$, $p=0.1$). This is possibly because the 5-a-day is usually labelled on food products containing fruit and vegetables. Unlike typical vice food options (e.g., burger and cola), food items like celery may have already been recognized as virtue options and there might not be much room for 5-a-day label to further improve such good impressions.

[Table 5 here]

3.3 Logit regression model and Linear regression model

In the logit regression model, calorie overestimation was set as the baseline. **Table 6** shows if the age increase by one year, it is 1.002 times more likely for the consumer to underestimate the calorie content of a meal. A possible explanation for this could be that older people tend to be exposed to food information from various sources for longer periods. This information could come from food manufacturer's marketing, diet industry or government agency. In terms of nutrition information, the revelation of them will only achieve intended effect when consumers have a consensus about their value (Chandon & Wansink, 2012). For instance, trans-fat is invariably regarded as negative and fiber is always seen as positive(Chandon & Wansink, 2012). Otherwise, the exposure to massive vague and uncertain food information will cause more confusion, which increase the difficulty to make informed food decision (Chandon & Wansink, 2012; Schwartz & Borra, 1997). Being overwhelmed by enormous information, older people are more likely to use heuristics. It was also reported that the older adults use descriptive characteristics for food categorization more often than college students (Oakes & Slotterback, 2001).This consequently makes the older people more susceptible to the calorie estimation bias arising from averaging the virtue and vice food items in a meal.

[Table 6 here]

Another important finding is that the food combination of a meal has significant effect in both the likelihood of calorie underestimation and the estimated calorie content. Moreover, as illustrated in **Table 7**, the coefficient of this variable is greater than the other two significant variables in the linear regression model. It is therefore almost certain that specific food items in a meal play the most predominant role in calorie estimation. This broadly supports the work of other studies in this area linking food categorization with the inherent nature of food (Carels et al., 2006; Chernev, 2011; Chernev & David, 2010; Rozin et al., 1996). For example, fruit and vegetables tend to fall into the category of virtue because they are naturally regarded as healthy. On the contrary, snacks and fast food such as burgers and fries are always categorized as vice due to their inherently unhealthy nature.

When the calorie information is not available or consumers are using heuristics to make quick food decisions, such vice/virtue attributes of each food item in a meal are relied on to formulate an overall calorie estimation. And a general pattern in such heuristic decision-making process is virtue options are used to offset the vice options so the entire meal can be healthier (Chernev & David, 2010). In addition, Table 7 shows the presence of claims also has significant influence on estimated calorie content, and when the meal includes one more nutrition/health claim or 5-a-day campaign, its perceived calorie content will be lower. This further shows that nutrition and health claims can improve the health perception of the food products. This observation may support the hypothesis that nutrition/health claims can lower the calorie estimation by altering the intensity of vice/virtue of food items. And according to the t-test results reported earlier, their effect of reducing the intensity of vice is greater than the effect of enhancing the intensity of virtue.

The rationale for calorie underestimation stemming from the existence of virtue food options and nutrition/health claims is that people tend to believe healthier diets also contain less calorie content (Chandon & Wansink, 2007b). This reflects that consumers may usually overgeneralize the nutrition quality of diet and choose to ignore or simplify appropriate portion size to gain adequate nutrition. Calorie content alone is not able to represent good nutrition quality of a meal, other nutritional quality like sodium should also

be considered regarding health(Howlett et al., 2012). Moreover, the relationship between health and nutritional quality are usually curvilinear rather than monotonic, which means that there is an optimal intake for different nutrients rather than "the more the better" (Chandon & Wansink, 2012). This may further increase the difficulty of systematically balancing various nutrients in meals, especially when consumers are not sensitive to dose(Rozin et al., 1996).

Another major finding was that consumers interpretation of nutrition/health claims is not accurate. The health benefits of the labeled products tend to be exaggerated, and by comparison, the exaggeration is more substantial for unhealthy food like snacks. On the one hand, the nutritional quality involved in the claims is perceived to be more than the actual improvement. On the other hand, improvement of unmentioned nutritional quality can also be falsely perceived due to "halo effect"(Roe et al., 1999). Although legislation about nutrition and health claims emphasized the importance of consumer understanding, qualitative research may not provide evidence of adequate understanding (EU, 2006; Leathwood et al., 2007). As this study shows the presence of claims has significant influence in calorie estimation, the change of calorie estimation can potentially be a metric for future quantitative research of consumer understanding.

[Table 7 here]

4 Conclusion and implication

This paper strengthens the idea that the averaging bias can lead to underestimation of calorie content. This study has examined consumer's calorie estimation under the context of a meal containing different food combinations. When the meal includes virtue food options such as celery sticks and yogurt, its overall calorie content is always underestimated because the vice attribute of energy-dense option (e.g., burger) can be balanced by those virtue options. Such food combination design (vice + virtue) simulated the environment of developed countries where consumers have access to ultra-processed food products (vice) and comparatively more fresh fruits and vegetables (virtue). Their co-existence in

consumer's meal can lower perceived calorie content and subsequently cause overeating. This potentially explains the "obesity paradox" in developed countries.

Also, this paper has provided a deeper insight into the source of such bias. Behind the virtue/bad (good/bad) dichotomy is the adoption of a heuristic decision-making strategy. Even though consumers can easily access nutrition information of food from food packaging, website, or poster, they rarely use them in their food selection because it would be effortful and time-consuming to calculate every single item in the meal, especially when there are many food decisions to make. There is, therefore, a definite need for more user-friendly approaches to provide calorie information. A good practice might be the mobile applications which can be used to monitor and calculate nutrients intake (e.g., calories, sugar and fat) to maintain ideal body weight.

Another contributor of using heuristics is the bombardment of inconsistent food information from different sources. Profit-driven media and advertisers may even spread misleading nutrition information, which can cause confusion in consumers. In addition, this paper found it is also common for consumers to overrate their knowledge about calorie content of food and overgeneralize nutritional quality of food. Governmental institutions ought to use official dietary guidelines and awareness-raising campaigns to bridge such gap of nutrition knowledge in public. Also, the advertisements of energy-dense food products need to be rigorously controlled.

This paper only focuses on a few nutrition/health claims and 5-a-day campaign. Future research should explore whether their "halo effect" on calorie estimation can be generalized to various nutrition and health claims. In addition, an issue that was not addressed in this study was the reverse calorie illusion in the evaluation of meal 2. The stimuli used in meal 2 (a burger and three celery sticks) were similar to previous studies (Chandon & Wansink, 2007a; Chernev, 2011), however, the calorie content of this combination (virtue + vice) was overestimated in this study. Also, since the calorie content knowledge and body weight management awareness were reported by respondents, the data may not be able to reflect the actual level of these two variables. Lastly, we did not

ask whether there was the occurrence of chronic diseases and whether participants were following special diets.

Conflict of Interest: None

Data Availability Statement: The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Authors contribution

Ziang Wang: Conceptualization, Investigation, Writing - Original Draft, Writing - Review & Editing.

Toritseju Begho: Conceptualization, Writing - Review & Editing, Visualization, Supervision.

Ethical Guidelines:

The survey was approved after being assessed through the Research Ethics and Integrity procedure of the School of Geosciences, University of Edinburgh. Informed consent was obtained from all participants before conducting interviews or surveys. Participants were informed that they had the right to withdraw at any stage or to decline to participate and, should they choose to do so, that there were no implications. The authors did not ask for any personal information which could be directly used to identify individuals. The database was only assessed by the authors at University of Edinburgh/Scotland's Rural College (SRUC).

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This study provides evidence that calories in healthy/weight loss foods are

consistently underestimated, while those in unhealthy/weight gain foods were overestimated. This was important in building our argument on calorie illusion on different food types. Further, Carels et al. (2007) findings that dieters estimated calories in healthy foods more accurately and paid more attention to fat, calorie, and sugar content compared to non-dieters was useful in choosing the determinants of calories underestimation this paper.

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This study was useful in setting the argument on the dichotomy in food classification and its impact on calories estimation in this paper. The study showed that when assessing combined healthy and indulgent foods, consumers often underestimate total calories, averaging instead of summing them and that this bias arises from categorizing foods into "good" or "bad".

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Table 1: compositions of 5 meals

	Composition		Verbal description	Pictorial description	
Reference	Burger			 330.3kcal	
Meal 1	Burger	Zero sugar cola	Zero sugar		
Meal 2	Burger	Three celery sticks			
Meal 3	Burger	Three celery sticks	One portion of your 5-a-day, 5-a-day lowers your risks of serious health problems		
Meal 4	Burger	One pot of yogurt	Gut health, no added sugar, 0% fat		
Meal 5	Burger	Regular cola			

Calories content obtained from Burger King (2023); Tesco (2023)

Note: Food sizes was double cheese XL burger, 330ml cola can, 115g pot of yogurt, three celery sticks. The group sizes for the five meals were 113, 105, 102, 103, 100 for meals 1-5 respectively.

Table 2: Description of independent variables.

Independent variable	Description
Age	Prescreened age of respondent: 18-80
Gender	0, others/unknown
	1, Male
	2, Female
Education	Scale of 1-5 (ranging from 1, high school to 5, post-graduate)
BMI	Respondent's weight in kilogram per square of height in metres
Calorie knowledge	Scale of 1-10 (1 is I do not know, 10 is extremely well)
Weight management	Scale of 1-10 (1 is I do not care, 10 is extremely care)
Guilt	0, do not feel guilty after consuming unhealthy food
	1, feel guilty after consuming some unhealthy food
	2, feel guilty after consuming any unhealthy food
Food combination	1, burger + zero-sugar cola
	2, burger + celery
	3, burger + celery (5-a-day)
	4, burger + One pot of yogurt (115g)
	5, burger + regular cola
Health perception	Scale of 1-5 (1 unhealthy, 2 slightly healthy, 3 somewhat healthy, 4 moderately healthy, 5 very healthy)

Table 3: Summary of demographic composition of respondents

Characteristics	% of Total	Number
Gender		
a) Male	37.14%	195
b) Female	61.33%	322
c) Prefer not to say	0.38%	2
d) Other	1.14%	6
Age		
a) 18-37	51.00%	268
b) 38-57	36.00%	189
c) 58-77	12.60%	66
d) 78-97	0.40%	2
BMI		
a) under 18.5	2.15%	11
b) 18.5 and 24.9	42.86%	219
c) 25 and 29.9	30.14%	154
d) Over 30	24.85%	127
Highest level of education		
a) Primary school	0.00%	0
b) Middle school	0.76%	4
c) High school	30.29%	159
d) Undergraduate	41.52%	218
e) Post-graduate degree	24.00%	126
f) Vocational school	3.43%	18
Employment status		
a) Employee	61.33%	322
b) Self-employed	11.05%	58
c) Unemployed	6.10%	32
d) Student	5.90%	31
e) Stay at home husband/wife		
	8.19%	43
f) Other	7.43%	39
Percentage of total monthly income spent on food		

a) Below 10%	10.29%	54
b) 10-20%	36.95%	194
c) 21-30%	34.48%	181
d) 31-40%	10.86%	57
e) 41-50%	3.62%	19
f) 51-60%	3.05%	16
g) Above 60%	0.76%	4

Table 4: Eating habits, body weight awareness and calorie knowledge of respondents

Summary of individual information	% of Total	Number
Consciously check the nutrition facts panel of food		
a) Yes, I always check the nutrition facts panel regardless the nutrition/health claims	31.43%	165
b) Yes, but I am less likely to check the nutrition facts panel when the food has health/nutrition claims	30.86%	162
c) No, I rarely pay attention to either of them	37.71%	198
Feel guilty after consuming unhealthy food		
a) Yes for all food	8.95%	47
b) Yes for some food	69.52%	365
c) No	21.52%	113
Overall habits of eating healthy foods		
a) Poor	7.24%	38
b) Fair	35.62%	187
c) Good	41.71%	219
d) Very good	13.33%	70
e) Excellent	2.10%	11
Frequency of eating fast food or packaged snacks high in fat/salt/or sugar		
a) 6 or more times per week	10.86%	57
b) 4-5 times per week	19.05%	100
c) 2-3 times per week	40.00%	210
d) 1 time per week	18.48%	97
e) Less than 1 per week	11.62%	61
Body weight management awareness on a scale of 1 to 10 (1 is not care, 10 is extremely care)		
a) 1	1.71%	9
b)2	2.10%	11
c) 3	3.81%	20

d) 4	3.24%	17
e) 5	11.24%	59
f) 6	11.62%	61
g) 7	21.90%	115
h) 8	24.38%	128
i) 9	11.05%	58
j) 10	8.95%	47
Know about the calorie content of food (1 is do not know, 10 is extremely well)		
a) 1	5.14%	27
b)2	5.33%	28
c) 3	9.52%	50
d) 4	7.24%	38
e) 5	13.71%	72
f) 6	13.71%	72
g) 7	19.24%	101
h) 8	17.33%	91
i) 9	5.14%	27
j) 10	3.62%	19

Table 5: results of t-test on two groups of meals

		Mean calorie estimation/kcal	P-value
meal 1&5	1: burger + zero-sugar cola	451.48	<0.001
	5: burger + regular cola	673.49	
meal 2&3	2: burger + celery	463.16	0.1
	3: burger + celery (5-a-day)	403.98	

Table 6: Results of logit regression model of the determinants of calories underestimation

Independent variables	Odds ratio.		St.Err.	[95% Conf.	Interval]
Age	1.022	***	0.008	1.006	1.038
Gender	1.162		0.221	0.8	1.689
Education	0.948		0.076	0.809	1.109
BMI	0.989		0.012	0.966	1.013
Calorie knowledge	0.953		0.047	0.865	1.05
Weight management	1.038		0.059	0.928	1.16
Guilt	0.983		0.186	0.678	1.424
Food combination					
Meal 1	2.043	**	0.616	1.131	3.689
Meal 2	2.186	**	0.689	1.179	4.056
Meal 3	3.134	***	1.002	1.675	5.865
Meal 4	2.012	**	0.63	1.09	3.716
Health perception	1.038		0.103	0.855	1.259
Constant	0.491		0.347	0.123	1.964
Chi-square	27.760				
Prob > chi2	0.006				

Dependent variable: Overestimation/underestimation of calorie content
Meal 5 is reference
**** p<.01, ** p<.05, * p<.1*

Table 7: Results of linear regression model determinants of estimated calories

Independent variables	Coeff.		St.Err.
Age	-1.069		1.064
Gender	-21.413		26.328
Education	16.370		10.919
BMI	2.028		1.661
Calorie knowledge	-3.697		6.684
Weight management	4.260		7.739
Guilt	-0.495		25.673
Food combination			
Meal 1	-218.061	***	42.402
Meal 2	-203.944	***	43.869
Meal 3	-260.246	***	43.091
Meal 4	-188.544	***	43.834
Health perception	-15.306		13.399
Constant	650.910		97.075
F-test	4.783		
Prob > F	0.000		
Mean dependent var	492.591		
SD dependent var	305.712		

Dependent variable: Estimated calorie content
Meal 5 is reference
**** p<.01, ** p<.05, * p<.1*

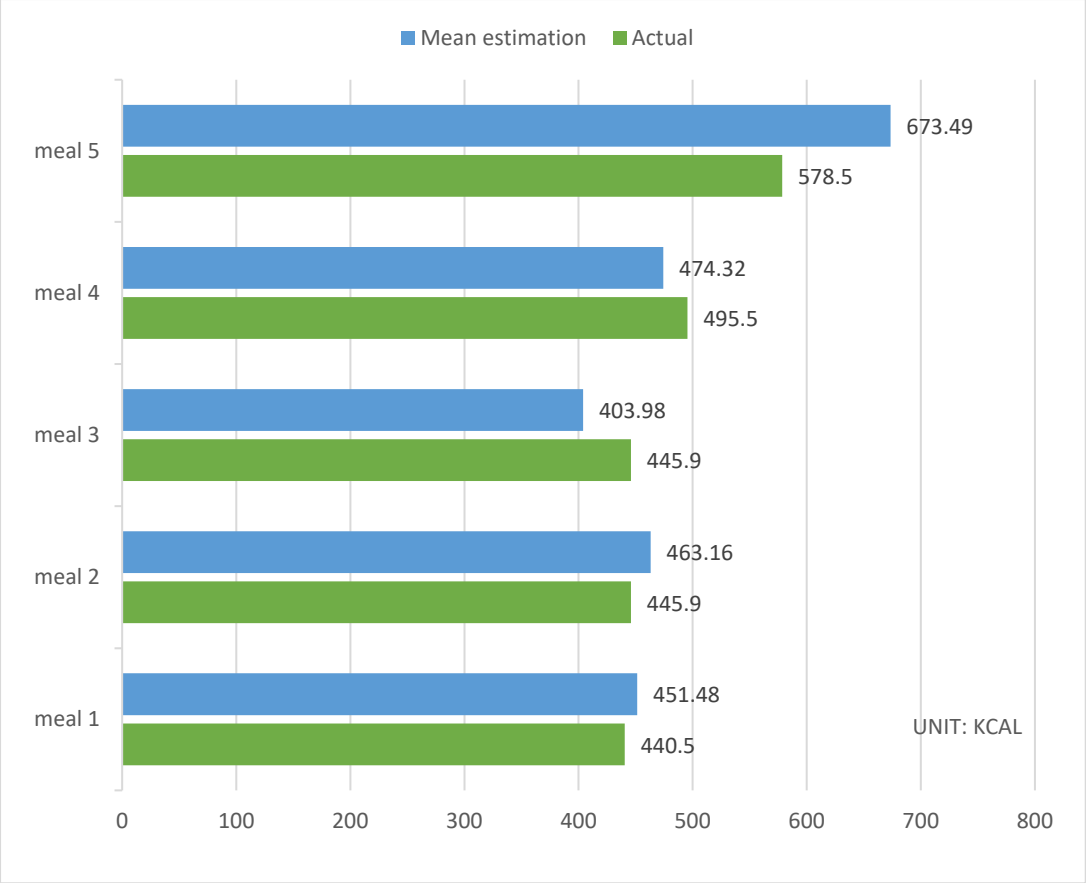

Figure 1, comparison between mean estimated calorie content and the actual calorie content.

Note: A One-sample t test suggests that the mean calorie content of this sample is statistically significantly different from the actual for meals 3 and 5