The Quarterly Journal of Experimental Psychology

ISSN: 1747-0218 (Print) 1747-0226 (Online) Journal homepage: http://www.tandfonline.com/loi/pqje20

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To cite this article: Natalie J. Gould, Elizabeth H. Zandstra & Martin R Yeomans (2017): Knowing too much: knowledge of energy content prevents liking change through flavour-nutrient associations., The Quarterly Journal of Experimental Psychology, DOI: 10.1080/17470218.2017.1373360

To link to this article: http://dx.doi.org/10.1080/17470218.2017.1373360

Accepted author version posted online: 31 Aug 2017.

Publisher: Taylor & Francis & The Experimental Psychology Society
Journal: *The Quarterly Journal of Experimental Psychology*
DOI: 10.1080/17470218.2017.1373360

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Knowing too much: knowledge of energy content prevents liking change through flavour-nutrient associations.

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Abstract

Associations between flavours and the consequences of ingestion can lead to changes in flavour liking depending on nutrient content, an example of flavour-nutrient learning. Expectations about the consequences of ingestion can be modified by information at the point of ingestion, such as nutritional labelling. What is unknown is the extent to which these label-based expectations modify flavour-nutrient learning. Since nutrient information can alter expectations about how filling a product would be, we hypothesised that labels predicting higher energy (HE) content would enhance satiety and so promote more rapid flavour learning. To test this, participants consumed either a lower (LE: 164kcal) or HE (330kcal) yoghurt breakfast on four separate days, either with no product label or with labels displaying either the actual energy content (Congruent label) or inaccurate energy (Incongruent label). Participants rated liking on all four days: on days one and four they could also consume as much as they liked, but consumed a fixed amount (300g) on days two and three. Both liking and intake increased with exposure in the HE, and decreased in the LE, condition when unlabelled in line with flavour-nutrient learning. In contrast, no significant changes were seen in either the Congruent or Incongruent label conditions. Contrary to predictions, these data suggest that flavour-nutrient learning occurs when there is an absence of explicit expectations of actual nutrient content, with both accurate and inaccurate information on nutrient content disrupting learning.

Keywords: *flavour, learning, expectation, reward*

Introduction

Humans acquire preference for a very diverse range of foods and drinks, expressed as flavour liking. Although many factors influence food choice (Köster, 2009; Meiselman, 1996; Nestle et al., 1998; Wansink, 2004), liking is a key driver of choice (Clark, 1998; Pliner & Mann, 2004; Prescott, Young, O'neill, Yau, & Stevens, 2002), and liking can increase intake (Bellisle, 2008; Yeomans, 1996). Thus understanding the nature of the processes underlying liking acquisition is important, especially in the context of a world-wide increase in obesity.

One of the learning mechanisms which is thought to drive acquisition of flavour liking is flavour-nutrient learning (Brunstrom, 2007; Gibson & Brunstrom, 2007; Yeomans, 2006). Here, associations between the flavour of the ingested product and the post-ingestive effects of the ingested nutrients become associated. Where the flavour predicts an adverse gastric event such as an acute gastric illness or the effects of motion sickness, the resulting association results in a profound and enduring flavour aversion (Arwas, Rolnick, & Lubow, 1989; Bernstein & Webster, 1980). However, where ingestion leads to a positive outcome such as the effects of caffeine (Rogers, Richardson, & Elliman, 1995; Yeomans, Durlach, & Tinley, 2005a) or the energy derived from ingestion of one of the macronutrients (Kern, McPhee, Fisher, Johnson, & Birch, 1993), a flavour preference can develop. Flavour nutrient learning (FNL) has been demonstrated very clearly in animal studies (Sclafani, 1999; Sclafani, 2004). There is also a growing body of research reporting FNL in humans (e.g. Appleton, Gentry, & Shepherd, 2006; Brunstrom & Mitchell, 2007; Mobini, Chambers, & Yeomans, 2007; Yeomans, Gould, Leitch, & Mobini, 2009), although there are also a number of studies which do not find changes in flavour liking and/or preference under conditions where changes would have been expected (e.g. Specter et al., 1998; Zandstra, Stubenitsky, De Graaf, & Mela, 2002; Zeinstra, Koelen, Kok, & de Graaf, 2009). There are numerous potential methodological explanations for these differences (lack of novelty for test CS, insensitive rating scales, etc.: see Yeomans, 2012), but FNL remains fairly elusive under human experimental laboratory conditions (Yeomans, 2012). Indeed, none of the three most recent studies attempting to find evidence of FNL in children by different approaches to fortifying vegetable purees found any evidence of increased liking after repeated consumption (Caton et al., 2013; Hausner, Olsen, & Møller, 2012; Remy, Issanchou, Chabanet, & Nicklaus, 2013).

The focus of this study was to consider for the first time how explicit knowledge of the nutrient content of a food, manipulated using realistic food labelling, modified acquisition of flavour liking through FNL. FNL has traditionally been interpreted as a form of classical conditioning (Rozin & Vollmecke, 1986; Rozin & Zellner, 1985), and there are strong claims mainly arising from the fear-learning literature that humans have to have explicit knowledge of the contingent relationship between the cue and outcome to be able to acquire classically-conditioned associations in general (Lovibond & Shanks, 2002). If this is true for FNL, it might be expected that explicit knowledge of the nutrient content would aid acquisition of FNL and so lead to more rapid liking acquisition. Indeed, it may be that variability in the extent to which training resulted in such explicit expectations might explain some of the variability of human FNL studies.

However, it has also been claimed that learning arises due to a mis-match between expected and perceived rewards, defined as a reward prediction error (Bayer & Glimcher, 2005). Originally founded in studies of neuronal function of dopaminergic systems in the nucleus accumbens, the reward prediction error idea has since been studied in relation to short-term reward delivery (see Glimcher, 2011). Applied to flavour-nutrient learning, it could thus be argued that learning progresses faster when there is a mis-match between the expected and experienced effects of ingested nutrients. Accordingly, explicit labelling of energy content might be predicted to retard rather than enhance the rate of change of liking for nutrient-paired flavours. In this context, previous research has shown clear effects of product labelling on overall product liking. For example, the use of more-evocative "gourmet" labelling increased actual liking for soups (Yeomans, Lartamo, Procter, Lee, & Gray, 2001). In relation to FNL, labelling can also modify the degree to which a product is expected to affect appetite: for example, women consumed more at a test meal following a yoghurt labelled as low-fat than after a yoghurt with similar energy content but labelled high-fat (Shide & Rolls, 1995), and the use of terms related to satiety as product names (e.g. "Stayfull" vs "Lighten": Chambers, Ells, & Yeomans, 2013) alter expectations about how filling a product will be. Likewise, explicit manipulation of the quantity of fruit contained in a smoothie drink altered the experience of appetite for up to three hours post-ingestion in the absence of actual nutrient differences (Brunstrom, Brown, Hinton, Rogers, & Fay, 2011), while directing individuals to explicitly think of a drink as a snack greatly increased the extent to which they responded to a covert manipulation of actual energy content (McCrickerd, Chambers, & Yeomans, 2014). All of these studies show that the immediate impact of a product on satiety is open to cognitive manipulation: experienced satiety appears to integrate these expectations with actual experienced effects of nutrient ingestion (Chambers, McCrickerd, & Yeomans, 2015). Given that it is the impact of the ingested product on appetite which is seen as the key driver for liking change through FNL, it thus follows that labels which modify the experience of post-ingestive satiety will alter the rate at which liking changes with repeated consumption, with the clear prediction for faster increases in liking where satiety is enhanced by product labelling. To our knowledge, these ideas have not been considered in relation to human FNL.

To test the effects of explicit knowledge of nutrient content on acquisition of flavour liking in humans, we therefore measured changes in liking for a novel flavoured breakfast either with higher (HE: 330 kcal) or lower (LE: 164kcal) energy content consumed either unlabelled, with a label that accurately displayed the served energy content (Congruent label) or a label that displayed the incorrect energy content (Incongruent label). If explicit information aided acquisition of the knowledge of the flavour-nutrient contingency, we predicted that liking would increase fastest in the Congruent labelled condition.

Method

Design

Participants were assigned at random to one of six breakfast conditions, combining two levels of energy (Lower Energy, LE, 164kcal or Higher Energy, HE, 330kcal) presented either Unlabelled, with a label that correctly labelled the energy content (Congruent label) or labelled with the wrong energy content (Incongruent label). They consumed their assigned breakfast on four non-consecutive days. Key measures were rated liking, estimates of how satiating the breakfast would be, intake and changes in rated appetite post-ingestion.

Participants

Participants were 60 healthy female volunteers, aged 18-29 (*M*= 21.45 ± 0.37) and with a mean BMI of 22.26 ± 0.40, mostly undergraduate students. Since restrained eating has been shown to influence responses in flavour-learning studies (Brunstrom, Higgs, & Mitchell, 2005; Brunstrom & Mitchell, 2007), all participants completed the Three Factor Eating Questionnaire during (TFEQ: Stunkard & Messick, 1985) recruitment and only those scoring less than seven on the TFEQ restraint scale were eligible to participate. Men were excluded to reduce variability in intake, given that men reliably consume more than women. Additional exclusion criteria were diabetes, allergy or aversion to any of the test ingredients, smoking more than 5 cigarettes per week and prior diagnosis of an eating disorder. The University of Sussex ethics committee approved the experimental design and protocol. The six test groups did not differ significantly in age $F(5, 54) = 0.10$, $p = .99$, BMI $F(5, 54) = 0.51$, $p = .77$ or restraint score $F(5,54) = 2.29$, $p = .06$ (Table 1).

Test foods

The test foods consisted of two yoghurt-based breakfasts of which the energy content was covertly manipulated (Table 2). These yoghurt-based breakfasts were produced in house using a base of a fat free natural yoghurt (Yeo Valley, UK), flavoured with almond extract (Supercook, UK), ground nutmeg (Schwartz, UK), banana flavouring (International Flavours and Fragrances) and yellow food colouring (Supercook UK). Cold stewed apple was mixed in with the yoghurt to provide a novel texture. Maltodextrin (Cargill) was added to the yoghurt for the high energy breakfast, and aspartame provided sweetness. Participants consumed an *ad libitum* amount of the test foods on days 1 and 4, and a fixed amount (300 grams) on days 2 and 3.

Labels

A fictitious brand name was created (Black Cap Dairy: Figure 1), with two versions of label used to manipulate expectations about the yoghurt. One was labelled as a 'Natural flavoured yoghurt- a natural high energy breakfast, 330kcal" (the correct calorie content of the HE yoghurt), while the second was labelled 'Natural low fat flavoured yoghurt – a natural low energy breakfast, 164kcal" (the correct calorie content of the LE yoghurt). These labels were presented as a laminated information sheet, explained as "these are the details of the product you have been served."

Expected Satiety

A measure of expected satiety, using the method of constant stimuli (Brunstrom, Shakeshaft & Scott-Samuel, 2008), was collected on test days 1 and 4. Participants were asked to select one of a series of portions of two breakfasts (crunchy nut cornflakes and porridge) which they expected would make them as full as they would expect to be having consumed their served portion. These ratings were made after tasting the breakfast but before it was consumed in full. The alternative portion sizes were presented in two booklets, one for each food, with each booklet containing a series of pictures of the target food increasing systematically in portion size. Based on the Brunstrom et al. (2008) methodology, image 10 was used as the standard, and this serving had the equivalent energy content of the median point between the LE and HE yoghurt breakfasts (247 kcal). Image 1 was 10% of this standard (24.7 kcal), image 2 was 20% of that amount, etc. Since the two foods did not have the same energy density, the visual portion size for the equivalent energy was larger with porridge. In order to ensure the final images for both foods were similar in visual serving size, the final image for the cornflake set was 987 kcal, giving 40 images for that food while the final image of porridge (number 30) was 740.1 kcal (3 times the calorie content of the median). The bowls used in the images were the same bowls as those that the yoghurt was served in.

Procedure

The overall testing procedure on the four test days is summarised schematicallty in Figure 2. Participants were required to report to the laboratory on four mornings, at a time between 0815 and 1000h, over a period of 1-2 weeks. Consent for participation was obtained at the start of the first session. Participants were instructed to eat nothing and consume only water from 2300h on each preceding evening. To obtain an estimate of their hunger on arrival, participants first completed a series of computerised visual analogue scale (VAS) ratings of their mood and appetite, (hungry, thirsty, full, lively, clear-headed, tired, nauseous, energetic, headachy, drowsy, calm). These were presented as 100pt visual analogue scales end-anchored with “Not at all <target rating>” and “Extremely <target rating>” with the question “How <target rating> do you feel right now?”, presented using Sussex Ingestion Pattern Monitor software (SIPM 2.014: University of Sussex). The yoghurt breakfast was then served, alongside the relevant label in the Congruent and Incongruent conditions. On all four test days, participants were instructed (via the computer) to take a taste of their yoghurt and then complete a series of flavour evaluations using 100pt VAS. The ratings were how pleasant, creamy, novel, bitter, sour, sweet, fruity, familiar they found the breakfast. Ratings were headed “How <target rating> is the drink?” and end-anchored with “Not at all <target rating>” and “Extremely <target rating>”. This was followed by an explicit question asking to enter a number representing the calories in the serving, which was a compliance check for the label conditions but also allowed an estimation of what participants estimated the energy content of these yoghurts to be in the Unlabelled conditions. On days 1 and 4, participants were also presented with the two expected satiety booklets at this time and were asked to select the picture showing the serving that they would expect to fill them up to the same extent as the portion of yoghurt they had received, completing this task prior to breakfast consumption but after tasting the yoghurt.

On days 1 and 4, participants were allowed to consume the breakfast ad libitum, with a refill provided once 250g had been consumed. On these two days, intake was monitored using SIPM, using a hidden digital balance (Sartorius BP4100) linked to the desktop PC, and this allowed the refill requirement to be measured surreptitiously as well as providing complete records of how much was consumed (Yeomans, 2000). On days 2 and 3, a fixed amount (300g) of the yoghurt breakfast was consumed. Participants were simply instructed to consume the served portion in full. Standardising intake on these days ensured consistent relationships between amount consumed and flavour on these training sessions: allowing free intake raised the risk that participants might adjust portion size to either increase overall energy intake in the LE or reduced intake in the HE condition as has been reported previously (Yeomans et al., 2009). On all four days, participants completed another set of computer mood and appetite VAS ratings immediately after finishing their breakfast, and they completed the same ratings using a paper version of the same questions one hour after leaving the laboratory (having refrained from eating and drinking except for water). On the final session, participants were debriefed, height and weight recorded, and they were reimbursed for their time either by a cash payment or course credits.

Data analysis

The key focus was on how liking for the flavour of the breakfasts changed across the four sessions depending on both energy content and label condition. Initial analyses confirmed there were no spurious significant differences in pleasantness between the six conditions on day 1 (using 1-way ANOVA), and as this was not significant, changes in liking on days 2, 3 and 4 were calculated by subtracting the relevant baseline from each day score for each participant. These scores were the contrasted between energy and label conditions with time (days 2-4) within participant, and rated hunger and dietary restraint as covariates, using repeated-measures ANOVA, with the focus on linear trends to test how pleasantness changed over conditioning trials.

Two further measures that could have changed through flavour-nutrient learning were expectations about how satiating the different breakfasts were and actual intake on Day 4 relative to the baseline (Day 1). For the expectation measures on Day 1 and 4, the actual energy content (kcal) of the selected picture for the two comparison foods was analysed, with these data contrasted across days (1 and 4) and comparison foods (cornflakes or porridge) within participants, and between the three label and two energy conditions between participants, using 2-way ANOVA with restraint as covariate. Intake on Days 1 and 4 were analysed similarly.

Results

Changes in flavour pleasantness

There was considerable individual variation in baseline pleasantness of the test breakfasts, although group contrasts confirmed that the consequent apparent group differences (Table 3) were not significant. As the focus was on how these evaluations altered with repeated consumption, pleasantness data were converted to change data for days 2-4 and these change data were examined to test for evidence of flavour-nutrient learning (Figure 3), in line with approaches used widely in the flavour-nutrient approach. As the prediction was for increased liking in the HE but not LE condition, the key test was the linear contrast with time. ANOVA revealed a significant 3-way interaction between label, energy and time for the linear contrast ($F(2,53) = 3.28$, $p=0.045$). To determine which conditions differed, follow-up analyses repeated this for each pair of label conditions. These analyses confirmed the significant 3-way interaction when contrasting Unlabelled and Congruent ($F(1,35) = 5.13$, $p=0.030$) and Incongruent and Congruent ($F(1,35) = 5.12$, $p=0.030$) conditions, but not Unlabelled and Congruent ($F(1,35) = 0.01$, $p=0.99$). No other effects were significant in these analyses. Analysis of each label condition separately confirmed an overall significant effect of breakfast energy in the Unlabelled condition ($F(1,54) = 9.84$, $p=0.003$), with a significant overall increase in pleasantness across days 2-4 of 15.7 in HE but minimal change (0.7) in the LE condition, but no significant effects of energy in the Congruent ($F(1,54) = 0.03$, $p=0.88$) or Incongruent ($F(1,54) = 0.64$, $p=0.43$) conditions. In these analyses, there were no significant effects of time in the Unlabelled or Congruent conditions but a near-significant effect of time in the Incongruent condition ($F(1,54) = 2.99$, $p=0.058$), with pleasantness tending to increase similarly over time in both HE and LE conditions. The only time when there was a significant difference between equivalent HE and LE conditions was on Day 4 in the Unlabelled condition.

Breakfast intake

Overall breakfast intake (g) varied depending on the energy content, label and day of consumption (3-way interaction: $F(2,53) = 8.63$, $p<0.001$: Figure 4). To determine the nature of this interaction, initial analysis contrasted intake on Day 1 alone, and found no significant differences. Consequently, changes in intake on Day 4 relative to Day 1 were calculated and analysed. Analysis of these change data found a significant energy x label interaction ($F(2,53) = 10.76$, $p < 0.001$). As with the pleasantness data, follow-up analyses repeated the analyses with each pair of conditions. The energy x label interaction was still significant both when contrasting Unlabelled and Congruent ($F(1,35) = 20.88$, $p < 0.001$) and Unlabelled and Incongruent ($F(1,35) = 11.83$, $p = 0.002$), but not when the two labelled conditions were contrasted ($F(1,35) = 0.58$, $p = 0.45$. When the overall change in intake was contrasted with zero, the only significant change was seen in the Unlabelled HE condition where intake on Day 4 was significantly greater than on Day 1, whereas intake for the equivalent LE condition was slightly, but not significantly, less on Day 4 than Day 1. There were no clear or significant changes in intake in the two labelled conditions. When intakes were converted into energy, more energy was consumed overall in the HE than LE condition because of the difference in energy density (HE 277kcal, LE 177kcal: $F(1,53) =$

52.06, p<0.001), but the 3-way interaction of energy, label and time remained significant (F(2,53) = 16.57, p<0.001).

Expected and actual satiety

Expected satiety was estimated as the energy content (kcal: Table 4) of the pictured serving of the two breakfast foods that were selected as being expected to be as filling as the yoghurt was expected to be. In all conditions and with both comparison foods, participants initially selected portions that were in excess of the actual energy content of the two trained yoghurt breakfasts (overall average chosen serving size on the first day was 407 ± 20 kcal, contrasting with actual servings of 330 kal, HE, and 165 kcal, LE). Analysis of these data only found a significant effect of time, where the chosen portion size decreased in all conditions regardless of actual energy content or label (main effect of time: F(1,53) = 11.97, p <0.001: kcal chosen on day four: 250 ± 13). When asked to input the estimated caloric content of their breakfast, for those in the two labelled conditions, 32/40 on Day 1 and 36/40 on Day 4 entered the correct value. The average caloric content estimated by the participants in the Unlabelled condition was 157 ± 16 kcal in the HE and 177 ± 13 kcal in LE, which did not differ significantly (t(17) = 0.93, p=0.36). These values were little changed on Day 4 (HE, 173 ± 17kcal: LE, 160 ± 22 kcal).

Actual satiety after ingesting the two different breakfasts could be estimated by the change in hunger from when people arrived to how hungry they felt one hour after breakfast consumption. Although overall rated hunger tended to decrease more after the HE (-52±3) than LE (-46±3) breakfasts, this was not significant overall (F(1,216) = 2.59, p=0.11), and there were no significant effects involving label or time in analysis of these hunger change data.

Discussion

In the absence of labelled information on energy content, liking increased in the HE but not LE condition in line with the predictions from FNL, and intake of the breakfast was greater on day 4 than day 1 in the Unlabelled HE condition. No such significant change in liking was seen in the Congruent label condition, suggesting that explicit awareness of the energy content of the breakfast either prevented acquisition of the flavour-nutrient relationship across the four test days or altered expression of any such association in terms of liking change. The effects of giving inaccurate information on energy content were more ambiguous: there was not significant difference in rated flavour pleasantness of the LE and HE versions when the Unlabelled and Incongruent conditions were contrasted, and both differed significantly from the Congruent condition, implying that learning was disrupted only when the expectation matched nutrient content. However, this conclusion needs caution as there was no actual difference in changes in rated pleasantness between LE and HE versions on any day in the Incongruent condition, but by day 4 liking was greater in the HE than LE condition in the Unlabelled condition (see Figure 3). Moreover, the effects on changes in breakfast intake were only seen in the Unlabelled condition.

The outcome of this study contradicts the prediction that explicit knowledge about energy content would enhance the rate of increase in flavour pleasantness through FNL. If that had been so, we would have expected a larger increase in flavour pleasantness in the Congruently labelled HE than Unlabelled HE conditions, whereas there was minimal change in pleasantness when the HE breakfast was accurately labelled. We would add a note of caution in interpreting this finding since the emphasis here was on changes in liking. While there were no significant differences in actual liking between conditions at baseline, average liking did vary between conditions (Table 2), with (spuriously) a trend for lower liking for the HE than LE breakfast in the Unlabelled condition, the one condition where liking did change over time. Although this does raise some concerns of the degree to which liking change in the Unlabelled condition can be seen as strong evidence of FNL, the parallel change in intake, where there was no baseline differences, does suggest that behavioural change here was driven by learning. Moreover, the lack of such baseline differences in liking or intake in the two labelled conditions, where liking was predicted to change, suggests that the failure to find evidence of increased liking through FNL in the predicted Congruent condition cannot be attributed to an artefact of baseline differences. It is also noteworthy that changes in intake were only evident in the Unlabelled condition, suggesting that both label conditions impacted eating regardless of whether they were congruent or not.

Why then might the Congruent label have interfered with, rather than enhanced, liking change through FNL? The outcome was much more in line with the idea that learning proceeds fastest when there is a mismatch between expected and observed outcomes, an idea originally encapsulated as the notion that surprise is key to learning (Dickinson, Hall, & Mackintosh, 1976) and then reinforced by evidence of the impact of anticipation on liking for primary tastes (O'Doherty, Deichmann, Critchley, & Dolan, 2002). Indeed, the similar increase in pleasantness in both LE and HE conditions when incongruently labelled fits with this mis-match idea: here there is a difference between expected and perceived nutrient intake, but in both cases nutrients are still consumed, and so there is a mis-match to promote learning and a positive outcome (energy ingestion) to promote liking. But as noted earlier, while the changes in liking in the Incongruent condition did not differ significantly from that seen in the Unlabelled condition, the actual data pattern (Figure 1) are less persuasive that liking was driven by actual differences in breakfast energy in that condition, and no changes in intake were seen in the Unlabelled condition, and the changes in liking did not map onto changes in intake, which only differed in the Unlabelled condition.

As well as evidence of a change in flavour pleasantness, participants increased their intake of breakfast only in the Unlabelled HE condition. This finding is in line with other studies of human FNL, where increased liking has been shown alongside increased intake (Yeomans, Gould, Mobini, & Prescott, 2008; Yeomans et al., 2009; Yeomans, Leitch, Gould, & Mobini, 2008; Yeomans, Weinberg, & James, 2005b). Thus the simplest explanation for this finding is that increased liking enhanced intake, given the well documented effects of palatability as a driver of intake (Yeomans, Blundell, & Lesham, 2004). It might then be questioned why intake did not also increase in the LE and HE Incongruent labelled conditions where liking also tended to increase. One possibility is that since the increase in liking here was lower, any effect on intake was missed due to a lack of power to detect changes. The increase in intake seen in the

Unlabelled HE condition also contradicts the effects predicted from ideas of learned satiety (Booth, 2009), where the suggestion is that meal-size is adjusted in anticipation of the subsequent effects of ingestion on appetite. Those ideas might have suggested that participants would learn that the HE breakfast was more filling, and the LE less so, and altered their intake in order to optimise the effects on ingestion (perhaps increasing intake of the LE version which might have been perceived as inadequately filling, and decreasing intake of the HE version if it was perceived as too filling). Since the only change in intake was an increase in the Unlabelled HE condition, this implies that these breakfasts were not so large that they generated the unpleasant post-ingestive effects shown in other studies to reduce liking and meal-size (Yeomans et al., 2009; Yeomans et al., 2005b), and so liking and consequent intake increased.

While rated pleasantness and intake were both modified by exposure, expectations of how satiating the breakfast would be did not change. The main method for assessing expected satiety here was the portion-size matching paradigm developed by Brunstrom and colleagues (Brunstrom & Shakeshaft, 2009; Brunstrom, Shakeshaft, & Scott-Samuel, 2008). Notably, other studies that have examined effects of repeated consumption of foods varying in energy content have also failed to detect changes in expected satiety using this method (Hogenkamp, Mars, Stafleu, & de Graaf, 2012; Yeomans, McCrickerd, Brunstrom, & Chambers, 2014), although one of these studies did find changes in rated satiety expectations (Yeomans et al., 2014), and so it may be that the method used here was too insensitive to detect subtle changes in satiety expectations. Here the decision to use only participants who score low in dietary restraint may have been influential since restrained eaters have been shown to show larger differences in satiety expectations (Brunstrom et al., 2008), and are more likely to respond to external cues such as labels and calorie/nutritional information than are unrestrained eaters (Ogden & Wardle, 1990). Indeed the finding that restrained eaters appear less responsive to FNL (Brunstrom & Mitchell, 2007) may in itself be a consequence of their over-reliance on external information. In this study the information provided by the label was selected to implicitly generate differences in expectations, but we did not include a manipulation check to evaluate the extent to which these labels did modify expected satiety: follow-up studies are thus needed to clarify further the relationship between expectations and the impact of labelling on FNL.

The overall finding of attenuated FNL in the Congruent label condition has very important implications as it would mean that nutrition labelling can impede (or overrule) learning. In a world where overconsumption is a key component of the worldwide increase in obesity, product labelling is a key element to behavioural change strategies aimed at promoting healthy food choice and reducing consumption of energy dense nutrients (such as fat and sugar). But since product liking is the primary driver of food choice (Clark, 1998), there is a risk that well-intentioned product labelling may reduce the impact of consumption on liking change and so inadvertently reduce the likelihood of consumers acquiring liking for reduced fat/sugar/energy products. Although further research is needed to confirm and extent the current findings to reformulated products and conditions of natural exposure, if the current finding is correct, this poses significant challenges to approaches to food labelling.

In summary, the present study is the first to text how labelled nutrient content modifies changes in liking and intake through FNL. The surprising finding, against our initial prediction, was that congruent labelling of nutrient content was associated with a lack of changes in liking and intake through repeated consumption, whereas liking and intake increased for the same product when higher in energy but Unlabelled. This surprising finding suggests explicit information about nutrient content modifies the reinforcing effects of ingested nutrients, and that liking only changes when expected and actual nutrient content are mismatched.

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Figure legends

Figure 1. The label stimuli used to indicate yoghurt nutrient content: top panel is an example of a higher energy label, lower panel is the lower energy label (note colours were counterbalanced).

Figure 2. A schematic summary of the test procedure on the four test days: on days 1 and 4 intake was ad libitum, and days 2/3 fixed.

Figure 3. Changes in the rated pleasantness of the high (HE: solid line and marker) and low (LE: dashed line and open marker) energy breakfasts across the four test days in the (A) unlabelled, (B) congruently labelled and (C) incongruently labelled conditions.

Figure 4. Total amount consumed expressed as bot weight (A) and energy (B) on the first and fourth study days in the three label conditions: unlabelled (unfilled bars) Congruent label (lightly shaded bars) and Incongruent label (Darker shaded bars).

Table 1. Demographic data for the participants in the six combinations of breakfast energy (higher or lower) and labelling (unlabelled, congruent and incongruent labels). All data are mean ± SEM, n = 10.

Parameter	Low Energy			High Energy		
	Unlabelled	Congruent	Incongruent	Unlabelled	Congruent	Incongruent
Age (years)	22 ± 1	21 ± 1	22 ± 1	22 ± 1	21 ± 1	22 ± 1
Body mass index (kg/m2)	23.5 ± 1.1	22.5 ± 1.2	21.6 ± 1.0	21.8 ± 0.5	21.7 ± 0.7	22.5 ± 1.3
TFEQ restraint	2.2 ± 0.5	2.1 ± 0.5	3.8 ± 0.6	3.6 ± 0.5	4.0 ± 0.6	3.4 ± 0.6

Table 2. Ingredients and energy content of the standard 300g serving of the higher energy (HE) and lower energy (LE) yoghurt-based breakfasts.

	HE yoghurt	*LE yoghurt*
Fat free natural yoghurt	206g	257g
Maltodextrin	51g	-
Aspartame	0.02g	0.05g
Apple	43g	43g
Ground nutmeg	2g	2g
Almond extract*	16 drops	16 drops
Banana flavouring*	2 drops	2 drops
Yellow food colouring*	2 drops	3 drops
Total weight	300g	300g
Total energy (Kcal (MJ))	328.8 (1.4)	164.5 (0.7)

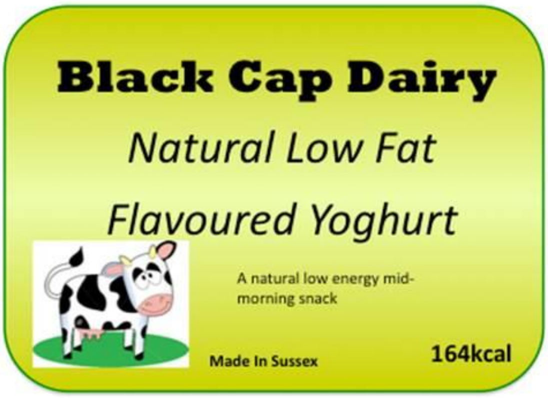
* *Drops were added using pipettes*

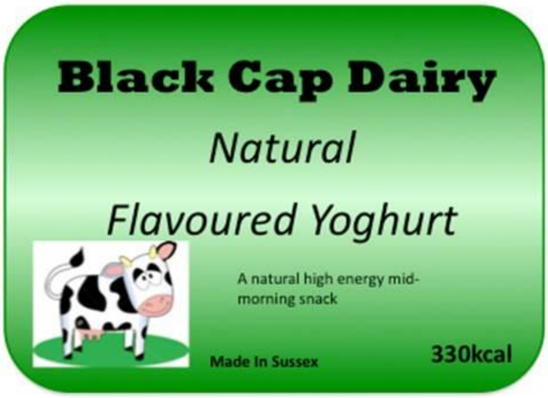
Table 3. Baseline liking of the two test breakfasts (lower energy, LE: higher energy, HE) in the three label conditions. Data are mean ± SEM, n=10.

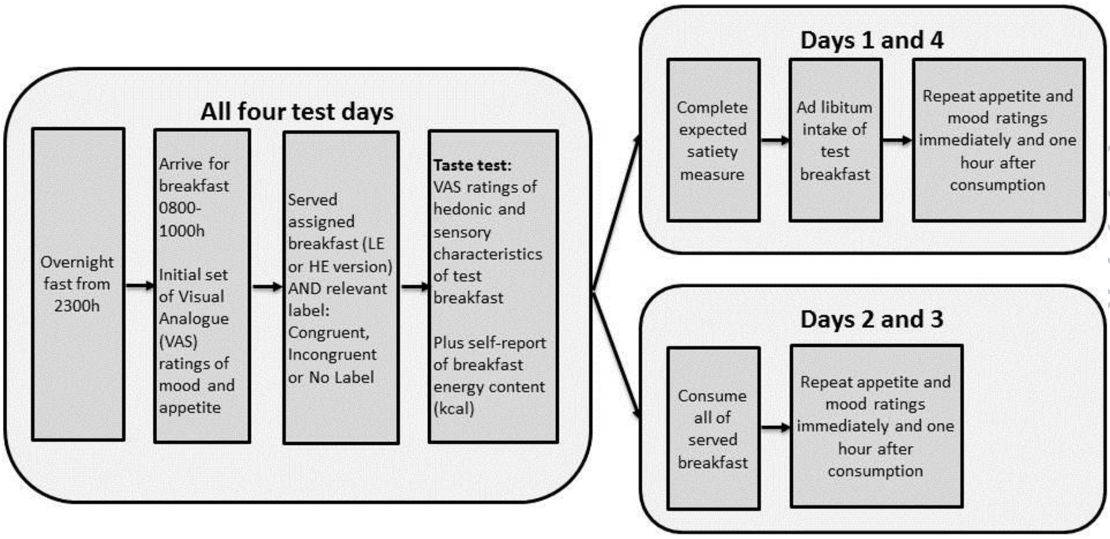
Label condition	LE	HE
Unlabelled	72 ± 10	55 ± 6
Congruent label	61 ± 9	63 ± 7
Incongruent label	61 ± 8	53 ± 9

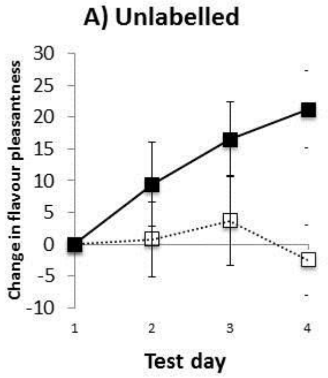
Table 4. Expected satiety estimates (kcal) based on selection of equivalent servings of two comparator foods on the first and final test day in the three label conditions.

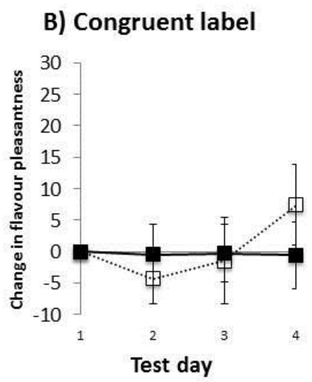
Yoghurt energy condition	Comparator food	Day 1			Day 4		
		Unlabelled	Congruent	Incongruent	Unlabelled	Congruent	Inc
Low	Porridge	436 ± 64	338 ± 55	427 ± 53	284 ± 31	234 ± 36	2
	Cornflakes	402 ± 30	323 ± 53	439 ± 68	264 ± 35	205 ± 27	2
High	Porridge	417 ± 74	456 ± 82	456 ± 58	262 ± 59	251 ± 44	2
	Cornflakes	422 ± 74	402 ± 67	370 ± 46	239 ± 53	247 ± 17	2

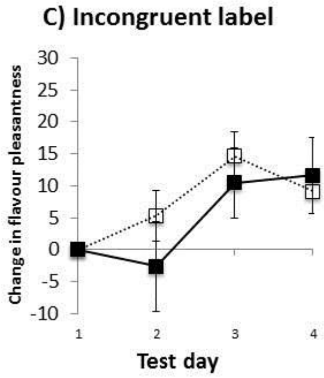

Black Cap Dairy
Natural Low Fat
Flavoured Yoghurt
A natural low energy mid-morning snack
Made In Sussex
164kcal

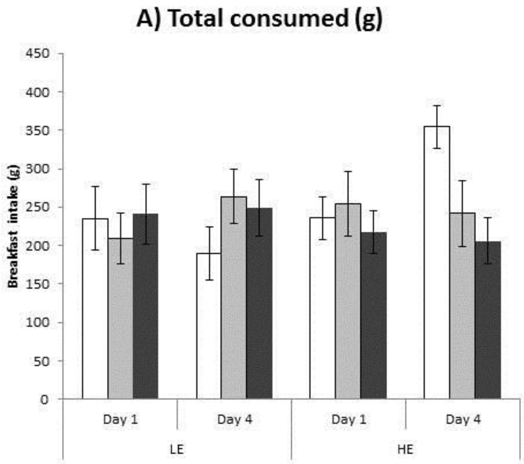

Black Cap Dairy
Natural
Flavoured Yoghurt
A natural high energy mid-morning snack
Made In Sussex
330kcal


All four test days
Overnight fast from 2300h
Arrive for breakfast 0800-1000h
Initial set of Visual Analogue (VAS) ratings of mood and appetite
Served assigned breakfast (LE or HE version) AND relevant label: Congruent, Incongruent or No Label
Taste test: VAS ratings of hedonic and sensory characteristics of test breakfast
Plus self-report of breakfast energy content (kcal)
Days 1 and 4
Complete expected satiety measure
Ad libitum intake of test breakfast
Repeat appetite and mood ratings immediately and one hour after consumption
Days 2 and 3
Consume all of served breakfast
Repeat appetite and mood ratings immediately and one hour after consumption

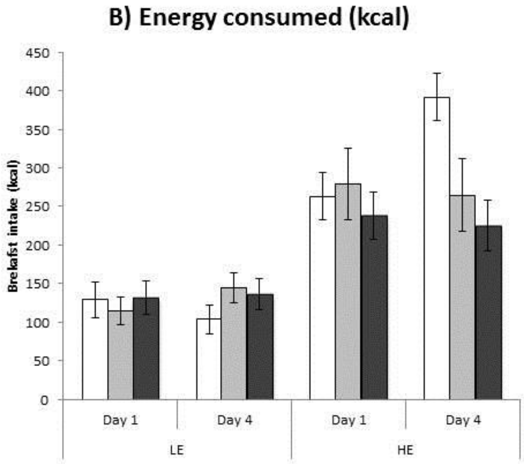

A) Unlabelled
Change in flavour pleasantness
30
25
20
15
10
5
0
-5
-10
1
2
3
4
Test day


B) Congruent label
30
25
20
15
10
5
0
-5
-10
Change in flavour pleasantness
1
2
3
4
Test day


C) Incongruent label
Change in flavour pleasantness
30
25
20
15
10
5
0
-5
-10
1
2
3
4
Test day



A) Total consumed (g)
Breakfast intake (g)
450
400
350
300
250
200
150
100
50
0
Day 1
Day 4
Day 1
Day 4
LE
HE


B) Energy consumed (kcal)
Brekafst intake (kcal)
450
400
350
300
250
200
150
100
50
0
Day 1
Day 4
Day 1
Day 4
LE
HE