**Abstract**

**Objective:**

The present study aimed to assess the effect of different types of breakfast cereal on portion size and the nutritional implications of potential under or overserving.

**Design:**

A cross-sectional analysis was performed using one BC from the 7 established BC manufacturing methods (flaking [F], gun puffed [GP], oven puffed [OP], extruded gun puffed [EGP], shredded wholegrain [SW], biscuit formed [BF], and granola). Participants were asked to pour cereal as if they were serving themselves (freepour). Difference between the freepour and recommended serving size (RSS) were calculated (DFR). The Friedman test followed by Dunn's multiple comparison test was used to test for a significant differences between cereal categories.

**Setting:**

City of Chester, North West of the UK

**Participants:**

Adults (n=169; n=110 female, 32±18 years)

**Results:**

Freepour values were greater than RSS for all categories of BC. Median values for denser cereals such as SW, granola and oats were significantly ($P$<0.001) greater than all other categories with granola having the highest median freepour value of 95 g. Median (and range of) DFR weight values for granola were significantly higher than other BCs (50.0 g [-24.0-267.0g], $P$<0.001). BCs with the lowest median DFRs were F1 (7.0 g [-20-63.0g]), GP (6.0 g [-26.0-69.0g]), EGP (6.0 g [-26.0-56.0g]), OP (5.0 g [-27.0-53.0g]), and BF (0.0 g [-28.2-56.4g]).

**Conclusions:**

The degree of overserving may be related to the type of BC with denser cereals more readily overserved. Encouraging manufacturers to reformulate cereals and improving their nutritional properties may have benefit in reducing excess energy intake.

**Keywords**

Breakfast, cereal, portion size, volume, obesity, sugar

## Introduction

Breakfast has traditionally been recommended as being one of the most important meals of the day. Inverse associations exist between consumption of breakfast and many health outcomes such as improvements in weight, risk of diabetes, and cardiovascular health to name a few[1-4]. However some of these relationships have been questioned, with findings suggesting important study design, age, sex, and meal composition effects[5-8].

Dietary recommendations in the UK suggest that breakfast should contribute approximately 20-25% of total energy intake, with breakfast foods being taken from the five main food groups of fruits and vegetables, milk and dairy, protein sources, low fat spreads and oils, and starchy foods (including cereals, pasta and bread). The fortification of cereals provides an important source of micronutrients for many individuals in the UK. However the most recent National Diet and Nutrition Survey (NDNS)[9] data suggest cereals and cereal products were the main source of free sugar in children aged 1.5-3 and 4-10 years, and in adolescents and adults were the second main source. Subsequently, Public Health England (PHE) included breakfast cereals (BCs) as a food which manufacturers should reduce sugar content in by 20% by 2020 in their Sugar Reduction Report[10].

BCs can be categorised into 'hot' and 'ready-to-eat' (RTE)[11]. Hot BCs, such as porridge, require further cooking. RTE BCs can be immediately consumed without added processing and are categorised by their processing method, rather than the grain used[11]. Different types of BCs from varying manufacturing methods include flaked, gun-puffed (GP), extruded gun-puffed (EGP), oven-puffed (OP), shredded wholegrain (SW) or biscuit formation (supplementary Table 1).Therefore it is possible to create products that vary in shape, size, colour, density, and volume of air.

There has been an indisputable increase of portion size in processed, energy-dense foods with little nutritional value[12, 13]. There is global concern that supersizing of food portions has altered the perception of what is healthy to consume[14]. Distorted portion perception has led to passive obesity where generations are successively heavier, resulting in normalisation of obesity[15]. Further evidence has demonstrated this same trend of increasing portion sizes over time in the UK[16-18] and in Europe[19]. The British Heart Foundation (BHF) released a report in 2013[20] suggesting that the discrepancy in recommended serving size (RSS) across products since 1993 has led to a distorted portion perception leading to consumer confusion. Indeed, when participants were asked to serve flaked BC (cornflakes) into a bowl, 88% portioned more than the RSS[20]. RSS of a product is determined by manufacturers, and differs to portion size which is the amount of food chosen to eat [18]. Evidence suggest that RSS can be exploited as a marketing strategy, with some products appearing more nutritious than a realistic portion[21]. Nevertheless, the European Breakfast Cereal Association[22] provide guidance for British BC brands on the RSS depending on product density, as well as considering the history of RSS for the BC and actual consumption data.

Research studying the typical portion sizes of flaked BC selected by young adults showed that the average portion exceeded recommendations by over 25%[23]. Additionally, rising obesity levels justify the importance of improved understanding of how physical food properties can affect portion size and energy intake. Literature has demonstrated the role of visual cues influencing portion size, including the image shown on packaging of BC, to the bowl size used[24], in addition to important properties such as density, volume and colour[25-27]. Rolls et al.[28] used the same type of flaked BC which was modified to decrease volume to 40%. As flake size reduced, volume of the serving decreased, and there was a significant increase in the weight of the flakes poured and the energy content of the portion. Therefore, the denser the

BC, the more energy was consumed. However a limitation of these types of study is the cereals used are relatively homogenous, and fail to consider how different types of BC with varying appearances and properties may influence portion size. The purpose of the present study was to determine whether different types of breakfast cereal influence portion size and as a result, energy and macronutrient content per serving.

## Methods

### Recruitment

Participants were recruited through randomised convenience and snowball sampling. A total of 8 recruitment sessions were conducted from the 20th of November 2019 to the 26th of February 2020 around Chester city centre. Subjects were told the purpose of the study was to investigate the portion size awareness of BCs.

Participants were excluded if they met any of the exclusion criteria or did not meet the inclusion criteria. All eligible participants signed an informed consent form before taking part in the study.

### Eligibility and screening

Participants were eligible to complete the study if they were older than 18 years old and regularly consumed BC. Participants were not eligible if they; had completed a Nutrition or Dietetics degree; were taking any medication known to have appetite-suppressing effects; were pregnant or lactating; were intentionally trying to lose weight; had any severe allergies; or had a previously diagnosed eating disorder. These factors were are likely to influence an individuals' perception of portion size.

### Anthropometric measurements

All participant's height and weight were measured in light clothing, without shoes. Upright height (m) was measured using a portable stadiometer (SECA, Leicester Height Measure) and recorded in metres (m) to the nearest 0.01m. Weight (kg) was measured using a portable electronic scale (SECA, 877) and recorded to the nearest 0.1kg. Body mass index (BMI) was calculated as weight divided by height squared ($kg/m^2$).

**Procedure**

Participants were asked by the researchers to pour a serving of each BC as if they were to consume it at home. This was reported as the free-pour measure. A white, porcelain 650ml bowl (15 cm x 7 cm [diameter and depth, respectively]) was used through the testing and each participant used the same bowl for each measurement. The researchers identified 10 different types of BC (Table 1). The nutritional information for each product was obtained from the back of pack labelling and is displayed in Table 2. The BCs were presented in the same order for each participant and stored in a transparent three litre Tupperware® container. All bowls of BC were discretely weighed on an electronic kitchen scale (HoMedics Groups Ltd, Salter) and recorded to the nearest 1g. Neutral phrases were used throughout the process including words such as 'thank you' or 'next' to avoid the participant detecting verbal cues, which may have influenced portion size.

**Statistical analysis**

Analysis was carried out using GraphPad Prism (version 8.0.1). The difference between the freepour measure and the recommended serving size (RSS) was calculated. RSS was taken from the cereal packaging. The difference between the RSS and freepour value is referred to as the DFR. The DFR value was used to assess the impact the participants freepour measure would have on differences in energy, macronutrient, salt and fibre intake. Data was assessed for normality using the D'Agostino-Person omnibus K2 test. All data violated the assumption of normal distribution, therefore a non-parametric approach was adopted. All measured parameters in the study (freepour, DFR, energy, macronutrients, salt, fibre) were compared across cereal categories using the Friedman test followed by Dunn's multiple comparison to test for significance.

## Results

### Participant characteristics

Participant characteristics are shown in Table 3. A total of 222 participants were screened, of which 169 were eligible and completed the study (Figure 1). This was similar to previous research in this area[23].

Overall, 110 (65%) participants were female. The mean age (±SD) of participants was 32±18 years old. The mean BMI was 24.4 ± 4.4kg/m$^2$. The majority of participants were of White European Ethnicity (89%). Fifty three (53) participants were excluded (Figure 1).

### Portion sizes of the freepour serving

Data for freepour values are show in Figure 2A. The striking finding of our analysis is the substantial variation in freepour measures based on BC type. All categories measured were above the median RSS value of 30g. Median (and range of) freepour values for BC categories were 37.0 g (10.0-93.0), 48.0 g (9.0-102.0), 36.0 g (4.0-99.0), 36.0 g (4.0-86.0), 64.0 g (9.0-140.0), 41.0 g (5.0-108.0), 35.0 g (3.0-83.0), 95.0 g (21.0-312.0), 63.0 g (20.0-214.00, and 37.6 g (9.4-94.0) for F1, F2, GP, EGP, SW, OPC, OP, Granola, Oats, and BF, respectively. Median values for SW, granola and oats were significantly greater than all other categories with granola having the highest median freepour value of 95 g (Figure 2A).

### DFR for differing BC categories

Due to differences in freepour values between cereal types, we calculated the difference (DFR) between the freepour weight and the RSS (Figure 2B). A similar pattern in DFR weight was observed to that of the freepour measures. Median (and range of) values for DFR weight were 7.0 g (-20.0-63.0), 18.0 g (-21.0-72.0), 6.0 g (-26.0-69.0), 6.0 g (-26.0-56.0), 24.0 g (-31.0-100.0), 11.0 g (-25.0-

83.0), 5.0 g (-27.0-53.0), 50.0 g (-24.0-267.0), 23.0 g (-20.0-174.0), and 0.0 g (-28.2-56.4) for F1, F2, GP, EGP, SW, OPC, OP, Granola, Oats, and BF, respectively. The DFR for granola was significantly greater than all other categories (Figure 2B). This indicates that the granola cereal category was overserved to a greater extent when compared to all other categories. Median values for SW and oats were significantly higher than other cereal categories (Figure 2B). Similar to Figure 2A, differences were observed between F1 and F2 categories. Collectively, these data indicate that all types of BC analysed (apart from BF) were overserved by our participants.

**Consequences on energy and macronutrient intake**

Due the significant differences seen between different cereals in freepour and DFR measures, we sought to determine the impact this theoretically would have on the difference in energy and macronutrient content per serving. Figure 3 shows the difference in energy or specific macronutrients as a consequence of DFR. Positive values indicate higher amounts than what would be consumed if using the RSS.

For total energy intake (Figure 3A), the pattern between cereals was similar to that observed in figure 2 with all cereal categories showing a positive median DFR in energy. Apart from BF (Figure 3A). Importantly total energy content of the cereals is dependent on their nutrient content (show in table 2). Median (and range of) DFR values for energy were 26.5 kcal (-75.0-231.1), 67.5 kcal (-78.8-270.0), 21.4 kcal (-92.8-246.3), 22.9 kcal (-99.3-213.9), 87.4 kcal (-112.8-317.1), 42.0 kcal (-95.5-317.1), 19.4 kcal (-104.5-205.1), 257.5 kcal (-123.6-1375.0), 83.5 kcal (-72.6-631.6) and 0.0 (-102.1-204.2) for F1, F2, GP, EGP, SW, OPC, OP, Granola, Oats, and BF, respectively. The difference in energy for granola was significantly greater than all other cereal categories in the study (Figure 3A). As the majority of cereals types were overserved, this led to higher than recommended servings of energy.

Different patterns were observed when considering the DFR in total carbohydrate (Figure 3B). Median (and range of) DFR values for total carbohydrate were 5.9 g (-16.8-52.9), 15.7 g (-18.3-62.8), 4.4 g (-19.2-51.1), 4.3 g (-18.5-39.8), 16.8 g (-21.7-70.0), 9.2 g (-21.0-69.7), 4.3 g (-23.2-45.6), 22.5 g (-10.8-120.2), 13.9 g (-12.1-105.3) and 0.0 g (-19.5-38.9) for F1, F2, GP, EGP, SW, OPC, OP, Granola, Oats, and BF, respectively. There was no significant difference between F1, GP, EGP, OPC, OP and BF categories. F2, SW, and oats were significantly different to other categories. Granola had the highest median difference in total carbohydrate (22.5 [-10.8-120.2]) and was significantly greater than all other cereal categories (Figure 3B).

As cereals have been identified by PHE as a food group to reduce the sugar content of [10], considering the sugar content of the DFR is important, especially if achieving the 5% target for free sugar intake. Median (and range of) DFR values for sugar were 0.6 g (-1.6-5.0), 6.7 g (-7.8-26.4), 1.3 g (-5.7-15.2), 1.1 g (-4.7-10.1), 3.1 g (-4.0-13.0), 1.9 g (-4.3-14.1), 0.4 g (-2.1-4.2), 7.2 g (-3.4-38.2), 0.3 g (-0.2-1.9), and 0.0 g (-1.2-2.4) for F1, F2, GP, EGP, SW, OPC, OP, Granola, Oats, and BF, respectively. Median DFR values for sugar in F2 and granola were significantly greater than other categories of cereal (Figure 3C). F2 and OPC values for sugar were significantly higher than their counterparts F1 and OP, respectively.

Median DFR values for fat where broadly consistent across all cereal categories, apart from granola (Figure 3D). Total fat DFR did not differ significantly between F1, F2, OP and BF groups (Figure 3D). Median (and range of) values were 0.1 g (-0.2-0.6), 0.1 g (-0.1-0.4), 0.1 g (-0.5-1.2), 0.3 g (-1.2-2.6), 0.4 g (0.6-1.8), 0.2 g (-0.5-1.6), 0.1 g (-0.3-0.6), 15.2 g (-7.2-80.9), 1.6 g (-1.4-12.18), and 0.0 g (-0.6-1.1) for F1, F2, GP, EGP, SW, OPC, OP, Granola, Oats, and BF, respectively. Granola showed the largest range of values for DFR for total fat, with the median value being significantly higher than all other categories (Figure 3D).

Saturated fat DFR did not differ significantly between F1, F2, GP, OP and BF groups (Figure 3E). Median (and range of) DFR values for saturated fat were 0.0 g (0.0-0.1), 0.0 g (0.0-0.1), 0.0 g (-0.1-0.2), 0.1 g (-0.2-0.5), 0.1 g (-0.1-0.3), 0.1 g (-0.2-0.8), 0.0 g (-0.1-0.2), 0.2 g (-0.1-0.8), 0.2 g (-0.2-1.7), and 0.0 g (-1.2-0.3) for F1, F2, GP, EGP, SW, OPC, OP, Granola, Oats, and BF, respectively. Oats and granola had the highest median DFR values for saturated fat, and whilst there was not significant difference between these groups, both were significantly higher than the other cereal categories (Figure 3E).

Similar to other categories, granola had the highest DFR for protein with a median (and range of values) of 6.2 g (-0.2-17.92) (Figure 3F). Values for other categories were 0.5 g (-1.4-4.4), 0.8 g (-1.0-3.2), 0.4 g (-1.9-4.9), 0.6 g (-2.4-5.3), 2.6 g (-3.4-11.0), 0.7 g (-1.6-5.3), 0.4 g (-1.9-3.7), 2.4 g (-2.1-17.9) and 0.0 g (-3.4-6.8) for F1, F2, GP, EGP, SW, OPC, OP, Oats, and BF, respectively. SW and oats displayed similar values and both differed significantly to other cereal groups (Figure 3F).

NDNS highlight cereals as being an important source of fibre for all age groups[(9)] and hence consuming more than the RSS may have some advantages, especially if this leads to increased consumption of nutrients such as fibre. There was no significant difference in the DFR for fibre between F1, F2, GP, EGP, and OP (Figure 3G). Median (and range of) values were 0.2 g (-0.6-1.9), 0.4 g (-0.4-1.4), 0.5 g (-2.2-5.8), 0.5 g (-2.3-5.0), 3.1 g (-4.0-13.0), 0.3 g (-0.8-2.5), 0.1 g (-0.5-1.1), 3.5 g (-1.7-14.4), and 0.0 g (-0.3-0.84) for F1, F2, GP, EGP, SW, OPC, OP, Granola, Oats, and BF, respectively. Median values for SW and oats did not differ significantly. The DFR for fibre was significantly higher in the granola group compared to all other categories (Figure 3G).

Salt content of cereals is an important but often overlooked aspect of their nutritional profile. Indeed in 2019 Action on Salt revealed that out of 77 cereals analysed, 1 had salt content greater than 1.5g/100g, and 65 contained a salt content between 0.3-1.5g/100g[(29)]. An increased portion size (vs.

the RSS) would lead to greater consumption of salt. In our analysis, median (and range of) values for salt DFR were 0.1 g (-0.2-0.7), 0.2 g (-0.2-0.6), 0.0 g (0.0-0.0), 0.1 g (-0.2-0.5), 0.2 g (-0.2-0.7), 0.1 g (-0.2-0.5), 0.1 g (-0.3-0.5), 0.0 g (0.0-0.0), 0.0 g (0.0-0.0), and 0.0 g (0.0-0.0) for F1, F2, GP, EGP, SW, OPC, OP, Granola, Oats, and BF, respectively. Categories F1, EGP, OPC, OP, and granola did not differ significantly from each other (Figure 3H). In comparison to other nutrients, granola and oats had the lowest DFR for salt. SW and F2 had the highest DFR values for salt. Collectively, our data show that regular consumers of cereal over-serve, with more dense cereals such as SW, granola and oats being the most difficult to portion accurately. As a result of increased portion sizes, the impact on energy and nutrition content is also substantial, and varies depending on the type of BC consumed.

**Discussion**

The present study aimed to establish if different types of BCs were associated with differing portion sizes. Our study has demonstrated that our study population overserved the majority of BC types tested, with denser BCs being overserved to a greater degree than less-dense varieties.

Previous studies had shown that individuals had a tendency to pour larger portions than the RSS[20, 23]. However, limitations to these studies were that they had only compared portions of flaked BC and therefore the findings could not be applied to other types of BC. SACN[30] published that there was a tendency for high-fibre BCs to be overconsumed, however only compared two categories. In our analysis the majority of BC appeared to be overserved regardless of the type of BC. The exception to this were the pre-portioned BF category, indicating that they were easier to portion. However, the degree of over-portioning tended to be associated with the physical characteristics of the BC, consistent with previous literature showing the influence of physical properties of food on portion size[27, 28]. To improve portion size awareness, the size of a portion should become more prominent on packaging and there should be standardisation across types of BCs. Alternatively, CEEREAL should consider updating the suggested RSS to reflect a realistic portion size, which would subsequently change the traffic light nutritional information often found on the front of the pack. Unrealistic portion sizes may mislead the consumer to perceive a product as nutritious, leading to larger portion sizes[31] and although PHE[10] included BCs in their sugar reduction programme, government policy should place more pressure on manufacturers of high-energy dense BC, such as granola, to reformulate products to improve their nutritional value.

Differing densities of BC may explain some of the findings in our study. CEEREAL[22] consider product densities when proposing the RSS. Figure 3.2 showed that the smallest median DFR in weight after BF originated from BCs including OP, OPC, GP and EGP, as well as F1, all of which were the less dense types of BCs. It appeared that the participants' tendency to overserve had less of an impact on serving weight with these types of cereal. In contrast, denser cereals such as granola, SW and oats, had a significantly larger DFR indicating a greater degree of over-serving and larger portion sizes. Incorporation of air into products and hence a reduction in density produces a decrease in energy consumed(27). Two other studies also demonstrated how differing volumes of isoenergetic preloads influenced satiety in men as a result of overestimating calorie content(32, 33). These studies showed that there was a dissociation between volume, weight and energy content, therefore altering the individual's perception of portion size. The BCs with a RSS of 30g and a greater volume of air (GP, EGP, OPC and OP) had a significantly smaller median DFR suggesting a smaller difference between the manufacturers RSS and what the participants served themselves. Collectively, this may suggest that reducing the density of cereal may be an effective way to decrease energy intake.

Portion size is an important determinant of energy intake and given that all but one types of BC tested lead to a degree of over-serving, we examined the impact this had on energy and macronutrient intake. Previous literature has demonstrated that when portion size increases, energy intake increases significantly and is sustained over subsequent days i.e. no compensation(34). In our analysis, granola had the largest freepour measure and was also the most energy dense. Consequently, this led to a large DFR of energy, supporting previous research showing that high-energy dense foods have the largest effect on energy intake(34). SW and oats are less energy dense and had a significantly smaller DFR for energy than granola. The significance of these observations can be seen when comparing our findings to the Government recommendations from the One You campaign, specifically the advice that breakfast should provide approximately 400 kcal(35). Our analysis suggests that individuals regularly consuming the median portion size for granola would be consuming approximately 490 kcal at breakfast per day, exceeding these recommendations. This does not include other food items consumed at breakfast, such as milk on the cereal, which would increase the energy intake further and contribute to weight gain if this was not compensated for at other mealtimes. Therefore, government policy should encourage companies manufacturing high-energy dense BC to reformulate products to reduce energy density, as a result of lack of portion size awareness. Research has shown that energy density is not strongly associated with food choice, therefore reformulation may not influence market sales, but increase health benefits[36].

In our study the types of cereal F1, OP, and BF were low in fat, saturated fat, and total sugar, but contained modest amounts of protein and fibre. However this same cannot be said about categories such as F2, GP, EGP, and OPC, especially considering sugar. As a single meal, breakfast contributes more to the daily intake of carbohydrate, total sugars, and less to total daily intake of protein, total fat, saturated fat and fibre[37]. Breakfast remains an important source of micronutrients, especially in young children and less so in adolescents[38]. However our finding that freepour measures were larger than the RSS is significant, and the importance of breakfast combined with the potential for a significant source of sugar suggests that BC reformulation should be taken seriously. For context, the median serving for granola in our study would see an individual consume almost 14 g of sugar, with a similar observation seen in the F2 group (approximately 18 g per serving). If the median portion size of granola was routinely consumed, it would likely have negative implications on nutritional health as it may contribute to excess energy and sugar intake[39]. There needs to be substantial drive to reformulate breakfast products to improve their nutritional composition and contribution to overall nutrient intake.

Similar to sugar, salt content of cereal is also a cause for concern and has been recently reported as such[29]. Salt intake remains an important public health nutrition target, and as a nutrient has strong links to cardiovascular health, specifically blood pressure[40]. Indeed the gradual reduction of salt intake in the UK diet is speculated to be one of the contributing factors to lower stroke and coronary heart disease mortality[41], with salt content of BCs decreasing as part of the Governments incremental targets[42]. The salt reduction targets published in 2020[43] continue to include BCs as a category, with new targets that are lower than the previous recommendations published in 2017. Thus it is essential that cereal products be reformulated to meet these new goals. In our study the cereals used had a wide range of salt contents, ranging from <0.01g/100g to 1.12g/100g. For children, reducing salt intake can be a challenge, especially as previous studies have suggested that whilst a low-salt BC can be consumed for up to 8 weeks, there is still no significant change in salt preference[(44)]. In contrast, low-salt interventions in adults of 5 and 12 months duration do lead to changes in salt preference when trialled using various foodstuffs[(45, 46)]. For salt-reductions to be effective in children, it would seem that improving educational awareness of the consequences of excessive salt is more effective than simply reducing the salt content of a product[(47)], and a combination of the two would have the greatest impact on health. Combined with result from Action on Salt[(29)], our finding that all cereal categories were overserved suggests there is considerable potential for consumers to be unknowingly consuming more salt at breakfast than they are perhaps aware of.

Despite the negative consequences of over serving highlighted above, there is genuine potential for the overserving finding in our study to be exploited for public health benefit. Overserving BCs may contribute positively to an individuals health by increasing the consumption of carbohydrates, fibre and protein, in addition to vitamins and minerals that the cereal product was fortified with. For example, the larger portions seen in SW, granola and oat categories – whilst leading to higher amounts of energy and sugar in the present study – could be used to increase intake of fibre, protein, and micronutrients if such products were reformulated correctly. Considering fibre as an example, current UK intakes are woefully inadequate with the majority of every age group not meeting the revised target of 30g/day[(9)]. Indeed recent analyses have shown the importance of higher cereal fibre intake on markers of cardiovascular health such as lower waist-hip ratio[(48)], in addition to being inversely associated with prevalence of diverticular disease[(49)] and inflammation[(50)]. Thus there is scope to utilise the over-serving effect seen in our study to improve the population's intake of nutrients such as fibre, however this requires input from manufacturers to reformulate products accordingly, reducing energy density of BC and simultaneously lowering salt and sugar.

There are important limitations to our study that warrant discussion. Our study population were well-educated with 30% of participants having achieved an undergraduate degree or equivalent. A previous study has demonstrated that educational level influences nutritional knowledge[51], with additional work suggesting increased nutritional knowledge positively influences dietary intake, usually of fruits and vegetables[52], and is associated with a higher frequency of breakfast consumption[53]. Thus further studies should be performed in more diverse socioeconomic groups. Moreover, 68% of participants were classified as students. Studies have acknowledged that some students have a less healthful lifestyle than the general population[54]. The time of day that participants of the study was not controlled, due to the project's time constraints. This meant that the researchers could not control the satiety and hunger of the participants, which may have influenced portion size. Future studies are required to determine how the portion size awareness of BCs differ in a fasted state, which is likely when individuals would serve BCs. It is also important to note that whilst our participants were familiar with all cereals used in the study, they were not required to habitually consume each type of cereal. Stipulating this as a requirement for the study would have negatively impacted on recruitment and also introduced more variation by removing the repeated measures aspect of the study design. Lastly it must be recognised that the cereals analysed in our study do not fully represent fully the variety seen within each type of BC category.

In conclusion, the present study contributes to existing literature that consumers have a tendency to overconsume BC. However, we show that this is not uniform across different cereal types and the degree of overserving varies with the type of BC used. Granola, the most energy dense BC, was associated with the least portion size awareness and hence greatest degree of overserving. This lack of portion size awareness may impact on nutritional health if routinely overserved, due to the high energy, fat and sugar content. The present study supports previous work showing that denser foods are associated with reduced portion size awareness as a result of the dissociation between volume, weight and energy content. Government policy should encourage manufacturers to update the RSS and standardise portion size across cereals, as well as acknowledge differences for adults and children. Product reformulation should be encouraged to both positively exploit the overserving seen in our study.

## List of Tables

**Table 1. BC products with corresponding brand, manufacturing method and RSS.**

| Abbreviated Name of BC | Manufacturing method of BC | Brand | RSS (g) |
|---|---|---|---|
| F1 | Flaked | Kellogg's | 30.0 |
| F2 | Flaked and Frosted | Kellogg's | 30.0 |
| GP | Gun-puffed | Honey Monster | 30.0 |
| EGP | Extruded Gun-puffed | Kellogg's | 30.0 |
| SW | Shredded wholegrain | Nestle | 40.0 |
| OPC | Oven puffed | Nestle | 30.0 |
| OP | Oven puffed | Nestle | 30.0 |
| Granola | Granola | Dorset Cereal | 45.0 |
| Oats | Rolled | Sainsbury's | 40.0 |
| BF | Biscuit formation | Weetabix | 37.5 |

**Table 2. Nutritional information for the BCs**

| **BC** | Energy (kcal/100g) | Fat (g/100g) | SFA (g/100g) | CHO (g/100g) | Sugar (g/100g) | Fibre (g/100g) | Protein (g/100g) | Salt (g/100g) |
|---|---|---|---|---|---|---|---|---|
| **F1** | 378 | 0.9 | 0.2 | 84.0 | 8 | 3 | 7 | 1.12 |
| **F2** | 375 | 0.6 | 0.1 | 87.0 | 37 | 2 | 4.5 | 0.83 |
| **GP** | 357 | 1.8 | 0.3 | 74.0 | 22 | 8.4 | 7.1 | <0.01 |
| **EGP** | 382 | 4.7 | 0.9 | 71.0 | 18 | 8.9 | 9.4 | 0.84 |
| **SW** | 364 | 1.8 | 0.3 | 70.0 | 13 | 13 | 11 | 0.72 |
| **OPC** | 382 | 1.9 | 0.9 | 84.0 | 17.0 | 3.0 | 6.3 | 0.65 |
| **OP** | 387 | 1.2 | 0.4 | 86.0 | 7.9 | 2.0 | 7.0 | 1.00 |
| **Granola** | 515 | 30.3 | 3.3 | 45.0 | 14.3 | 7 | 12.3 | 0.03 |
| **Oats** | 363 | 7.0 | 1.0 | 60.5 | 1.1 | 8.3 | 10.3 | <0.01 |
| **BF** | 362 | 2.0 | 0.6 | 69.0 | 4.2 | 10.0 | 12.0 | 0.28 |

**Table 3. Participant characteristics**

| Characteristics | Participants (n=169) | |
|---|---|---|
| | Mean | Standard deviation |
| Age (years) | 31.7 | 17.52 |
| Weight (kg) | 69.5 | 15.3 |
| Height (m) | 1.68 | 0.86 |
| BMI (kg/m$^2$) | 24.4 | 4.4 |
| | n | % |
| Highest Qualification Achieved | | |
| None | 2 | 1.2 |
| GCSE or equivalent | 12 | 7.1 |
| A Level or equivalent | 85 | 50.3 |
| Higher Apprenticeship or equivalent | 3 | 1.8 |
| Foundation degree or equivalent | 1 | 0.6 |
| Degree with honours or equivalent | 17 | 10.1 |
| Master's Degree or equivalent | 17 | 10.1 |
| Doctorate or equivalent | 3 | 1.8 |
| Occupation | | |
| Student | 114 | 67.5 |
| Employed | 43 | 25.4 |
| Unemployed/retired | 12 | 7.1 |
| Ethnicity | | |
| White | 151 | 89.3 |
| Mixed/Multiple groups | 2 | 1.2 |
| Asian/Asian British | 8 | 4.7 |
| Black/African/Caribbean/Black British | 4 | 2.4 |
| Other | 4 | 2.4 |

**List of figures**

**Table legends**

**Table 1**

Weight shown in grams (g). Abbreviations: Recommended serving size, RSS; Breakfast cereal, BC; Flaked 1, F1; Flaked 2, F2; Gun-puffed, GP; Extruded Gun-puffed, EGP; Shredded wholegrain, SW; Oven-puffed coloured, OPC; Oven-puffed, OP; BF, Biscuit formation.

**Table 2**

Data shown in kilocalorie (kcal) and grams (g) per 100g. Abbreviations: Breakfast cereal, BC; Carbohydrates, CHO; saturated fat, SFA; Flaked 1, F1; Flaked 2, F2; Gun-puffed, GP; Extruded Gun-puffed, EGP; Shredded wholegrain, SW; Oven-puffed coloured, OPC; Oven-puffed, OP; Biscuit formation, BF

**Table 3**

Data shown as mean ± standard deviation for age, weight, height and BMI. Highest qualification achieved, occupation, and ethnicity shown as number (n) and %

## Figure legends

**Figure 2 Freepour and difference between Freepour and RSS**

Freepour (A) and difference between freepour and RSS (B). Data shown as median ± range. N=169 for 10 BCs. Flaked 1, F1; Flaked 2, F2; Gun-puffed, GP; Extruded Gun-puffed, EGP; Shredded Wholegrain, SW; Oven-puffed coloured, OPC; Oven-puffed, OP; Biscuit Formation, Biscuit. The dashed line in figure 1A represents median portion size of 30 g (based on our cereal sample). Categories with unlike letters were significantly different (P<0.001).

**Figure 3 Differences in potential nutritional intake based on participants freepour**

Data shown as median ± range. N=169 for 10 BCs. Energy (A), total carbohydrate (B), sugar (C), fat (D), saturated fat (E), protein (F), fibre (G), and salt (H). Flaked 1, F1; Flaked 2, F2; Gun-puffed, GP; Extruded Gun-puffed, EGP; Shredded Wholegrain, SW; Oven-puffed coloured, OPC; Oven-puffed, OP; Biscuit Formation, BF. Categories with unlike letters were significantly different (P<0.001).

## References


1. Ruddick-Collins LC, Johnston JD, Morgan PJ *et al.* (2018) The Big Breakfast Study: Chrono-nutrition influence on energy expenditure and bodyweight. *Nutr Bull* 43, 174-183.
2. Monzani A, Ricotti R, Caputo M *et al.* (2019) A Systematic Review of the Association of Skipping Breakfast with Weight and Cardiometabolic Risk Factors in Children and Adolescents. What Should We Better Investigate in the Future? *Nutrients* 11, 387.
3. Iqbal K, Schwingshackl L, Gottschald M *et al.* (2017) Breakfast quality and cardiometabolic risk profiles in an upper middle-aged German population. *European journal of clinical nutrition* 71, 1312-1320.
4. Williams PG (2014) The Benefits of Breakfast Cereal Consumption: A Systematic Review of the Evidence Base. *Advances in Nutrition* 5, 636S-673S.
5. Ardeshirlarijani E, Namazi N, Jabbari M *et al.* (2019) The link between breakfast skipping and overweigh/obesity in children and adolescents: a meta-analysis of observational studies. *Journal of diabetes and metabolic disorders* 18, 657-664.
6. Aanesen A, Katzmarzyk PT Ernstsen L (2020) Breakfast skipping and overweight/obesity in first grade primary school children: A nationwide register-based study in Iceland. *Clinical obesity*, e12384.
7. Rosato V, Edefonti V, Parpinel M *et al.* (2016) Energy Contribution and Nutrient Composition of Breakfast and Their Relations to Overweight in Free-living Individuals: A Systematic Review. *Adv Nutr* 7, 455-465.
8. Sievert K, Hussain SM, Page MJ *et al.* (2019) Effect of breakfast on weight and energy intake: systematic review and meta-analysis of randomised controlled trials. *BMJ (Clinical research ed)* 364, l42.
9. PHE (2018) National Diet and Nutrition Survey. Results from Years 7 and 8 (combined) of the Rolling Programme (2014/2015 to 2015/2016). https://www.gov.uk/government/statistics/ndns-results-from-years-7-and-8-combined (accessed 08 July 2020)
10. PHE (2017 ) Sugar Reduction: Achieving the 20%. A technical report outlining progress to date, guidelines for industry, 2015 baseline levels in key foods and next steps. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/604336/Sugar_reduction_achieving_the_20_.pdf (accessed 08 July 2020)
11. Institute MR (1995) Cereal Breakfast Food. https://www3.epa.gov/ttn/chief/ap42/ch09/bgdocs/b9s09-2.pdf (accessed 08 June 2020)
12. Nielsen SJ & Popkin BM (2003) Patterns and Trends in Food Portion Sizes, 1977-1998. *JAMA* 289, 450-453.
13. Piernas C & Popkin BM (2011) Increased portion sizes from energy-dense foods affect total energy intake at eating occasions in US children and adolescents: patterns and trends by age group and sociodemographic characteristics, 1977–2006. *The American Journal of Clinical Nutrition* 94, 1324-1332.
14. Benton D (2015) Portion size: what we know and what we need to know. *Critical reviews in food science and nutrition* 55, 988-1004.
15. Butland B, Jebb S, Kopelman P *et al.* (2007) Tackling Obesities: Future Choices. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/287937/07-1184x-tackling-obesities-future-choices-report.pdf (accessed 08 July 2020)
16. Benson C (2009) Increasing portion size in Britain. *Society Biology and Human Affairs* 74.
17. Church S (2008) Trends in portion sizes in the UK - A preliminary review of published information http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.397.8604&rep=rep1&type=pdf (accessed 08 July 2020)

18. Rippin HL, Hutchinson J, Jewell J *et al.* (2019) Comparison of consumed portion sizes and on-pack serving sizes of UK energy dense foods. *Appetite* 134, 193-203.
19. Steenhuis IHM, Leeuwis FH Vermeer WM (2009) Small, medium, large or supersize: trends in food portion sizes in The Netherlands. *Public Health Nutrition* 13, 852-857.
20. Foundation BH (2013) Portion Distortion Report 2013. https://www.bhf.org.uk/informationsupport/publications/policy-documents/portion-distortion-report-2013 (accessed 08 July 2020)
21. Kliemann N, Kraemer MVdS, Scapin T *et al.* (2018) Serving Size and Nutrition Labelling: Implications for Nutrition Information and Nutrition Claims on Packaged Foods. *Nutrients* 10.
22. (CEEREAL) EBCA (2008). http://ceereal.eu/images/technical-docs/CEEREAL_Portion_Sizes.pdf (accessed 08 June 2020)
23. Schwartz J & Byrd-Bredbenner C (2006) Portion Distortion: Typical Portion Sizes Selected by Young Adults. *Journal of the American Dietetic Association* 106, 1412-1418.
24. Tal A, Niemann S Wansink B (2017) Depicted serving size: cereal packaging pictures exaggerate serving sizes and promote overserving. *BMC public health* 17, 169.
25. McClain AD, van den Bos W, Matheson D *et al.* (2014) Visual illusions and plate design: the effects of plate rim widths and rim coloring on perceived food portion size. *International journal of obesity (2005)* 38, 657-662.
26. Van Ittersum K & Wansink B (2011) Plate Size and Color Suggestibility: The Delboeuf Illusion's Bias on Serving and Eating Behavior. *Journal of Consumer Research* 39, 215-228.
27. Osterholt KM, Roe LS Rolls BJ (2007) Incorporation of air into a snack food reduces energy intake. *Appetite* 48, 351-358.
28. Rolls BJ, Meengs JS Roe LS (2014) Variations in cereal volume affect the amount selected and eaten for breakfast. *Journal of the Academy of Nutrition and Dietetics* 114, 1411-1416.
29. Action On Salt (2019) Children's Breakfast Cereals STILL Shockingly High in Sugar with Nearly Half of Products Receiving a Red Label – Ban Cartoons on Unhealthy Breakfast Cereal Products. http://www.actiononsalt.org.uk/salt-surveys/2019/childrens-breakfast-cereals/#_edn1 (accessed 08 July 2020)
30. Scientific Advisory Committee on Nutrition (2015) Carbohydrates and Health. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/445503/SACN_Carbohydrates_and_Health.pdf (accessed 11 December 2020)
31. Labbe D, Rytz A, Godinot N *et al.* (2017) Is portion size selection associated with expected satiation, perceived healthfulness or expected tastiness? A case study on pizza using a photograph-based computer task. *Appetite* 108, 311-316.
32. Rolls BJ, Bell EA Waugh BA (2000) Increasing the volume of a food by incorporating air affects satiety in men. *The American Journal of Clinical Nutrition* 72, 361-368.
33. Rolls BJ, Castellanos VH, Halford JC *et al.* (1998) Volume of food consumed affects satiety in men. *The American Journal of Clinical Nutrition* 67, 1170-1177.
34. Rolls BJ, Roe LS Meengs JS (2007) The Effect of Large Portion Sizes on Energy Intake Is Sustained for 11 Days. *Obesity* 15, 1535-1543.
35. PHE (2018) Plans to cut excess calorie consumption unveiled. https://www.gov.uk/government/news/plans-to-cut-excess-calorie-consumption-unveiled (accessed 08 July 2020)
36. Brunstrom JM, Drake ACL, Forde CG *et al.* (2018) Undervalued and ignored: Are humans poorly adapted to energy-dense foods? *Appetite* 120, 589-595.
37. Gaal S, Kerr MA, Ward M *et al.* (2018) Breakfast Consumption in the UK: Patterns, Nutrient Intake and Diet Quality. A Study from the International Breakfast Research Initiative Group. *Nutrients* 10, 999.

38. Coulthard JD, Palla L Pot GK (2017) Breakfast consumption and nutrient intakes in 4-18-year-olds: UK National Diet and Nutrition Survey Rolling Programme (2008-2012). *The British journal of nutrition* 118, 280-290.
39. Livingstone KM & McNaughton SA (2017) Dietary patterns by reduced rank regression are associated with obesity and hypertension in Australian adults. *The British journal of nutrition* 117, 248-259.
40. Huang L, Trieu K, Yoshimura S *et al.* (2020) Effect of dose and duration of reduction in dietary sodium on blood pressure levels: systematic review and meta-analysis of randomised trials. *BMJ (Clinical research ed)* 368, m315.
41. He FJ, Pombo-Rodrigues S MacGregor GA (2014) Salt reduction in England from 2003 to 2011: its relationship to blood pressure, stroke and ischaemic heart disease mortality. *BMJ open* 4.
42. Pombo-Rodrigues S, Hashem KM, He FJ *et al.* (2017) Salt and sugars content of breakfast cereals in the UK from 1992 to 2015. *Public Health Nutrition* 20, 1500-1512.
43. PHE (2020) Salt Reduction Targets for 2024. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/915406/2024_salt_reduction_targets_070920-FINAL-1.pdf (accessed 11 December 2020)
44. Bobowski N & Mennella JA (2019) Repeated Exposure to Low-Sodium Cereal Affects Acceptance but Does not Shift Taste Preferences or Detection Thresholds of Children in a Randomized Clinical Trial. *The Journal of Nutrition* 149, 870-876.
45. Blais CA, Pangborn RM, Borhani NO *et al.* (1986) Effect of dietary sodium restriction on taste responses to sodium chloride: a longitudinal study. *Am J Clin Nutr* 44, 232-243.
46. Bertino M, Beauchamp GK Engelman K (1982) Long-term reduction in dietary sodium alters the taste of salt. *Am J Clin Nutr* 36, 1134-1144.
47. He FJ, Wu Y, Feng X-X *et al.* (2015) School based education programme to reduce salt intake in children and their families (School-EduSalt): cluster randomised controlled trial. *BMJ (Clinical research ed)* 350, h770.
48. Barrett EM, Amoutzopoulos B, Batterham MJ *et al.* (2020) Whole grain intake compared with cereal fibre intake in association to CVD risk factors: a cross-sectional analysis of the National Diet and Nutrition Survey (UK). *Public Health Nutrition* 23, 1392-1403.
49. Aune D, Sen A, Norat T *et al.* (2020) Dietary fibre intake and the risk of diverticular disease: a systematic review and meta-analysis of prospective studies. *European Journal of Nutrition* 59, 421-432.
50. Sang S, Idehen E, Zhao Y *et al.* (2020) Emerging science on whole grain intake and inflammation. *Nutrition Reviews* 78, 21-28.
51. Hendrie GA, Coveney J Cox D (2008) Exploring nutrition knowledge and the demographic variation in knowledge levels in an Australian community sample. *Public Health Nutrition* 11, 1365-1371.
52. Spronk I, Kullen C, Burdon C *et al.* (2014) Relationship between nutrition knowledge and dietary intake. *British Journal of Nutrition* 111, 1713-1726.
53. Matsumoto M, Ishige N, Sakamoto A *et al.* (2018) Nutrition knowledge related to breakfast skipping among Japanese adults aged 18–64 years: a cross-sectional study. *Public Health Nutrition* 22, 1029-1036.
54. Sprake EF, Russell JM, Cecil JE *et al.* (2018) Dietary patterns of university students in the UK: a cross-sectional study. *Nutrition Journal* 17, 90.