



## Measuring Lunchtime Consumption in School Cafeterias Using Digital Images

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1 **Measuring Lunchtime Consumption in School Cafeterias Using Digital Images:**  
2 **A Validation Study.**

3

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16

**Abstract**

17

This study tested the validity of a digital image capture measure of food

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consumption suitable for use in busy school cafeterias. A small research team

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recorded children's lunchtime consumption in one primary and one secondary school

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over seven working days. Participants' ( $N = 258$ ) lunchboxes or dinner trays were

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photographed pre- and post-consumption, and food items served were weighed pre-

22

and post-consumption, for comparison. Using standardised digital images,

23

consumption of each food item was estimated to the nearest 10% to calculate the

24 approximate weight consumed in grams. Results indicated that, for each food  
25 category, (i) consumption estimates based on images were accurate, yielding only  
26 small differences between the weight- and image-based judgments ( $Median_{BIAS} =$   
27 0.15-1.64 grams, equating to 0.45-3.42% of consumed weight), and that (ii) good  
28 levels of inter-rater agreement were achieved, ranging from moderate to near perfect  
29 (Cohen's  $\kappa = .535-.819$ ). This confirmed that consumption estimates derived from  
30 digital images were accurate and could be used in lieu of objective weighed measures.  
31 Our protocol minimised disruption to daily lunchtime routine, kept the attrition low,  
32 and enabled better agreement between measures and raters than was the case in the  
33 existing literature. Accurate measurements are a necessary tool for all those engaged  
34 in nutrition research, intervention evaluation, prevention, and public health work. We  
35 conclude that our simple and practical method of assessment should be used with  
36 children across a range of settings, ages, and lunch types.

37 (232 words)

38 **Key Words:** Validation, Consumption, Digital Photography, Cafeteria, School,  
39 Visual Estimation, Children, Nutrition, Diet.

40

41

## Introduction

42 In the past two decades, the onset of affordable, easy to use, high-resolution  
43 digital cameras have provided the researchers with a convenient new tool for dietary  
44 assessment. The appeal of this method includes creation of objective records which  
45 can be examined in several ways, by more than one independent coder, and to a  
46 greater level of detail, than is the case with visual estimation of consumption  
47 performed 'in situ' [1]. Using digital image capture, small teams of observers, causing

48 minimal disruption in busy dining environments, can capture the information on  
49 portions (servings) and plate waste from a large cohort of participants [2]. In  
50 principle, this information can subsequently be stored, re-analysed, and shared. Such  
51 improvements in reliability and replicability have led to digital image collection  
52 replacing or enhancing the more traditional methods for estimating consumption,  
53 including direct methods (such as visual estimation by a group of observers present at  
54 meals) and indirect methods (such as using dietary diaries or recall); manifest in the  
55 emergence of recent reports that are investigating how images can complement other  
56 forms of dietary assessment as prompts and as complementary data sources [3, 4, 5].  
57 However, the present study considers the use of digital image capture to measure  
58 consumption behaviour in a more controlled environment, where images are not  
59 recorded freely, directly by consumers, but in a controlled and highly replicable  
60 setting.

61 Many studies have used image-assisted visual estimation without reporting the  
62 validity or reliability of this method [6, 7], but several validation reports have also  
63 appeared in the literature. Some of these publications have examined the reliability of  
64 image-based visual estimation methods [8-10], but seldom do they examine the  
65 method's accuracy against a criterion measure. Others have compared estimates based  
66 on digital images to weighing of the foods under controlled lab conditions. For  
67 example, Williamson et al. [11] have used a contrived scenario where plates of food  
68 were arranged by the researchers and plate waste mimicked by subtracting precisely  
69 weighed amounts of foods, and Sabinsky et al. [12] assessed accuracy in consumption  
70 estimations from images of typical sandwiches that children may bring from home to  
71 school, though these sandwiches were created by researchers in order to simulate a  
72 standard home-provided lunch. These studies show that, in principle, raters' estimates

73 based on digital images can be sound, but they cannot test the validity of data  
74 collection protocols performed under free-living conditions.

75 Pouyet, Cuvelier, Benattar and Giboreau [13] addressed this issue by  
76 examining image-based dietary assessment in a geriatric setting, and Nicklas et al.  
77 [14] looked at utilising caregivers as data-collectors, using iPhones to remotely  
78 photograph total weekly food consumption of preschool children. However, these  
79 studies have administered their protocols in potentially less chaotic environments,  
80 such as in the home or elderly care home dining areas, where there may be more  
81 opportunities to capture images, without the time constraints typical of a school  
82 cafeteria. Taylor, Yon, and Johnson [15] attempted to validate digital image capture in  
83 a real-life school canteen setting; however, though they report that digital image-  
84 capture has the potential to be used as a method of collecting nutritional data, they  
85 focused on fruit and vegetable consumption and did not consider other food types.  
86 Hanks, Wansink and Just [16], considered a broader spectrum of food types in their  
87 attempt to validate the use of digital image-capture, however, data were only collected  
88 during one lunch period, and available foods were those that are typically distributed  
89 in pieces and do not mix, such as chicken nuggets, sandwiches, or cookies, which are  
90 very different from ‘wet’ foods like stews or curries or baked beans that are sauce-  
91 based and spread on the plate, mixing with other ingredients, and which make the  
92 plate waste much more difficult to estimate.

93 In a systematic review of evidence for image-assisted dietary assessment,  
94 Gemming et al. [17] called for better validation studies using criterion measurement  
95 and protocols capable of capturing information in free-living research with children  
96 and adolescents. To our knowledge, only one recent investigation reported to have  
97 validated their method of visual estimates based on images against weighed measures

98 with school-provided meals' data collected in two primary school cafeterias [18],  
99 albeit using very generous agreement criteria.

100         Considering this gap in the literature, the present study had been designed to  
101 test the validity of a simple but versatile protocol for collection of consumption data  
102 in free-living cafeteria environments, in primary and secondary school settings, and  
103 for meals provided both by caterers and by parents.

104

105

## **Method**

106 **Aim**

107         This study was designed to test the validity of the use of digital image-capture  
108 as a method of nutritional data collection in busy school cafeterias, by (i) comparing  
109 estimates of consumption from digital images to weighed measures, and (ii)  
110 establishing inter-rater reliability of image-based estimates.

111 **Participants**

112         Following parental consent, 131 children from a rural primary school in North  
113 Wales and 127 children from an urban secondary school in the West Midlands took  
114 part. Both samples were well gender balanced (67 females in primary and 59 in  
115 secondary school) and represented a wide range of ages: 5-10 years old for primary  
116 (with 24 children in year 1; 25 in year 2; 23 in year 3; 20 in year 4; and 29 in year 5)  
117 and 11-18 years for secondary school (30 in year 7; 17 in year 8; 35 in year 9; 23 in  
118 year 10; and 19 in year 13). Participants were of a predominantly Caucasian origin,  
119 reflecting the demographics of their regions. Nineteen children (7%) were excluded  
120 because of incomplete data (e.g. no post-consumption image was captured), leaving a  
121 final sample of 239 participants. Each child contributed data for one lunchtime meal.

122 **Materials**

123 To capture images, 4 digital cameras were used (Fujifilm Finepix, 16 mega  
124 pixels, Model no. AX650). To standardise image capture, cameras were positioned on  
125 tripod stands (Tiffen Davis and Sanford, Vista EXPLORERV 60-Inch Tripod), with  
126 tape measures and protractors available to ensure correct set-up; the camera was  
127 approximately 45cm away from the plate, and at a 45 degree angle. This ensured that  
128 images contained consistent size and depth information necessary for coding.

129 Food items were either displayed on paper plates for lunchbox meals, or  
130 plastic school dinner trays. Plain white paper participant identification tags were  
131 attached to lunchboxes. White self-adhesive participant identification labels were  
132 attached to red metallic wrist bands given to each participant to wear during  
133 lunchtime, and to the plate/tray for later coding of the food and waste in each image.  
134 Non-latex gloves were worn at all times by researchers when handling food items.

135 **Procedure**

136 Data were recorded over four consecutive days (Monday – Thursday) in the  
137 primary school, and three consecutive days (Monday – Wednesday) in the secondary  
138 school. On these days, researchers arrived at the school prior to the registration period  
139 and set up a data collection area in the school gym. Then, one researcher entered each  
140 participating classroom during their registration period to collect lunchboxes,  
141 distribute participant identification labels (placed on wristbands), and attach  
142 additional participant identification labels to corresponding lunchboxes (if children  
143 had brought lunch from home). Those children who ate school dinners were told they  
144 would be given another sticker at lunchtime to put on their dinner tray. Researchers  
145 then described what participants would be asked to do at lunchtime.

146 Pre-consumption images and weights were then taken for each food item  
147 provided to the children. The protocol differed depending on whether the participant  
148 had a lunchbox or was given a school dinner.

149 *Lunchboxes.* Participants' lunchboxes were collected during registration and taken to  
150 the study area to be photographed. The contents of each box were spread on a paper  
151 plate. They were clearly visible and any items that could be unwrapped (e.g.  
152 sandwiches in tin foil or cling film) were exposed for the purpose of the image. Those  
153 items that could not be unwrapped (e.g. yogurts) were photographed and weighed in  
154 their wrapping, and the weight of each wrapping type (e.g. small yogurt pot) was  
155 deducted from the pre-weight record. Similarly, if an item was served in an unusual  
156 container (e.g. a thermos), the lid was removed for the purpose of the pre-  
157 consumption image, the whole container was weighed, and the weight of the  
158 container was deducted from this when a post-consumption measurement was  
159 obtained (at this point, any waste food could be emptied into a plastic cup in order to  
160 obtain the true weight of the container and returned to the container once it had been  
161 weighed). Items were then individually weighed and these weights were recorded.  
162 Those items that were comprised of more than a single component (e.g. a 'ham  
163 sandwich') were weighed as a single item, and weights of fillings were approximated  
164 based on separate measurements (see below). Lunchboxes were restored and returned  
165 to participants after morning break time.

166 *School dinners.* Estimate food measurements were calculated by asking caterers to  
167 serve researchers five portions of every food item available to children. Each portion  
168 was weighed on a plastic dinner tray and from this a mean was calculated for each  
169 food item. The portion that was closest to the mean for that food item was  
170 photographed (to be used as a reference for a typical portion). At lunchtime,  
171 participants were instructed to come to researchers after they had been served their

172 lunch, but before they sat down to eat, so that a pre-consumption image could be  
173 recorded for each child. One researcher was stationed at the end of the dinner queue  
174 to collect pre-consumption images, with a second researcher collecting post-  
175 consumption images positioned at the back of the dinner hall, by the waste bins, to  
176 protect against attrition from children disposing of waste food before it had been  
177 photographed. Tripods and cameras were set up prior to lunchtime commencement to  
178 be clearly focussed on an area on the table in front of them, so that dinner trays could  
179 easily be slid into focus, and an image captured, in a matter of seconds.

180         At lunchtime, all children sat down to eat as usual. Once the participants had  
181 finished eating, they handed their lunchbox or dinner tray to the researchers  
182 positioned at the back of the hall. Researchers photographed the dinner trays or  
183 contents of each lunchbox, and weighed each remaining food item individually (in the  
184 same manner as the pre-consumption data collection) before returning lunchboxes to  
185 participants or disposing of plate waste and returning dinner trays to the cafeteria  
186 staff.

## 187 **Data Processing and Coding**

188 *Weighed consumption measures.* For each child, consumption was calculated by  
189 subtracting post-consumption weight from estimated pre-consumption weight, (or  
190 known pre-consumption weight stated on branded snack packaging), for each  
191 recorded food item.

192 *Consumption estimates from digital images.* Utilising images collected during our  
193 unpublished pilot work, consumption analysis training protocol was developed for the  
194 present study. A representative sample of images from the pilot data set, showing a  
195 variety of home- and school-provided lunches and the associated plate waste, were  
196 coded jointly and then independently by a pair of raters (who had also been present at

197 school sites for data collection). The percentage consumed for each food item was  
198 estimated to the closest 10% (on an 11-point scale, from 0-100% consumed) using the  
199 pre- and post-consumption images. Successful completion of the training, manifest in  
200 the raters perfectly matching their ratings on over 90% of items, was achieved in  
201 approximately two working days. Following training, the lead researcher coded all  
202 data; to calculate inter-rater agreement, a second rater independently coded 40% of  
203 the total food items. Each participant's meal took approximately 30 seconds to  
204 estimate the percentage of each food item consumed, with an additional minute to  
205 convert these percentages into estimate weights.

206         Next, these percentage consumption estimates were converted to weights. The  
207 weight in grams for each food item in lunchboxes was judged by referring to product  
208 information published by the manufacturer (e.g. a Nutri-grain ® soft baked fruit  
209 cereal bar weighs 37g according to published product information, and so this was the  
210 weight recorded for Nutri-grain ® bars and supermarket own-brand varieties). Where  
211 this information was unavailable (e.g. for sandwiches), an average sandwich weight  
212 was calculated from displayed product information (e.g. the average "medium" slice  
213 of bread weighs 40g, the average "small" bread roll weighs 60g), and weighing  
214 samples (e.g. making 5 cheese sandwiches and weighing the components  
215 independently to estimate an average sandwich filling weight for commonly presented  
216 food items). For example, the average cheese sandwich on sliced bread was estimated  
217 to weigh 100g in total, with additional fillings (e.g. cheese and ham) increasing the  
218 estimated weight by 20g per filling, or 5g per salad filling (e.g. cheese and lettuce).  
219 Participants were also often presented with pieces of fruit, and so estimates were  
220 calculated from an average sized piece of fruit (e.g. an average apple weighs 70g,  
221 with 60g edible flesh, minus 10g for core; an average 'snack size/kids size' apple  
222 weighs around 50g with 40g edible flesh).

223           Following this protocol, it was possible to estimate the weight of each food  
224 item that children consumed in grams. For example, if a participant was judged to  
225 have consumed 70% of a Nutri-grain ® bar then 26g was consumed, or if a participant  
226 consumed 80% of a mean 64g portion of carrots then 51g was consumed.

227 *Preliminary data analyses.* All data were inputted into the IBM Statistical Package  
228 for the Social Sciences (SPSS) version 22. Where the first and second coder disagreed  
229 on how much of a food item was consumed by 10%, the estimation from the first  
230 coder was taken, and where they disagreed by more than 10%, the mean value  
231 between the two estimates was selected by researchers and was used to calculate the  
232 estimated weight consumed.

233           Total weights of food consumed by each participant were calculated by adding  
234 the weights from each recorded item. Next, to provide more detailed validation  
235 measures, all food items were allocated to one of four broad categories: (i) Main  
236 Starch item; (ii) Fruit and Vegetable; (iii) Meat, Dairy, and Wet foods (stews, curries,  
237 pasta sauce etc.); and (iv) Snack foods. These categories were based on similarity in  
238 the way the food items appear on a plate (e.g. compact [a potato] or spread [baked  
239 beans]); the approximate weight of servings (e.g. a Snack [crisps] weigh less than a  
240 Main Starch item [jacket potato]); and the approximate volume of the food items. All  
241 food items were categorised prior to analysis into a category that best represented  
242 their properties. For example, a yogurt could be considered a common snack, but was  
243 categorised as dairy since its volume and density is more typically shared by Meat,  
244 Dairy, and Wet Foods (such as beans or custard) than by those in the Snack category  
245 (such as crisps); sandwiches, though potentially containing foodstuffs from other  
246 categories, were considered a Main Starch item, as the majority of their weight and  
247 volume was bread – a starchy food stuff. All categories were broad so that they may  
248 contain enough data items to sufficiently power the subsequent analyses.

249 For lunchboxes, the Main Starch was typically a sandwich, whilst for school  
250 dinners it was more varied, with potatoes, pasta, rice, and pizza regularly presenting.  
251 In the Fruit and Vegetable category, a typical lunchbox portion included bananas,  
252 apples, and cucumber, whilst participants that ate school dinners were more likely to  
253 be served peas, sweetcorn, or carrots. Meat, Dairy, and Wet food items in lunchboxes  
254 were typically yogurts or cocktail sausages, whilst commonly presenting items in  
255 school dinners included sausages, custard, and baked beans. Finally, in lunchboxes,  
256 regularly presented Snack items included packets of crisps, cake bars, and cookies,  
257 whilst for school dinners they included shortbread and brownies, often provided as the  
258 'sweet'.

## 259 **Statistics and Sample Size Calculations**

260 As all data between groups were positively skewed, Mann-Whitney U tests  
261 were used to identify differences between groups (e.g. Primary/Secondary;  
262 Lunchbox/School Dinner meals), and the Median ( $M$ ) was used as the measure of  
263 central tendency. One sample t-tests were used to identify any significant differences  
264 between consumption estimations derived from digital-images and the criterion  
265 measurement.

266 *Comparing weight- and image-based data.* Bland-Altman plots were used to assess  
267 the agreement between the criterion and the image capture method. Previous  
268 published research utilising this analysis does not typically publish sample size  
269 calculations, though a sample of  $N=100$  would promote a sensitive analyses [18], and  
270 so all samples on which a Bland-Altman analysis was conducted exceeded  $N=100$ .  
271 Percent relative error (PRE) is a measure of precision, and is a ratio of the absolute  
272 error (the difference between two measurements) to the size of the actual measure,  
273 expressed as a percentage:

274 
$$\delta = 100\% \times \eta = 100\% \times \frac{\epsilon}{|v|}$$

275 Where  $\delta$  = PRE,  $\eta$  = relative error,  $\epsilon$  = absolute error (digital image estimate –  
 276 criterion measure [actual] value), and  $|v|$  = criterion measure value. This was used to  
 277 consider the acceptability of the magnitude of the bias.

278 *Model Accuracy.* Two data mining calculations were performed to establish the  
 279 accuracy of the model: Root Mean Square Error (RMSE) and Root Relative Squared  
 280 Error (RRSE). Accordingly, accuracy can be operationalised as the distance between  
 281 the estimated and or observed values and the true value (Walther & Moore, 2005, p.  
 282 817)<sup>1</sup>.

283 Root Mean Square Error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (Predicted_i - Actual_i)^2}{N}}$$

284  
 285 Root Relative Square Error:

$$E_i = \sqrt{\frac{\sum_{j=1}^n (P_{(ij)} - T_j)^2}{\sum_{j=1}^n (T_j - \bar{T})^2}}$$

286

287 Where  $P_{ij}$  is the predicted value and  $T_j$  is the target value and  $\bar{T} = \frac{1}{n} \sum_{j=1}^n (T_j)$

288 *Determining inter-rater agreement.* Cohen's  $\kappa$  was used to identify the level of  
 289 agreement on visual consumption estimates using images between raters, and we  
 290 ensured it was sufficiently powered [19].

291 
$$\kappa \equiv \frac{p_o - p_e}{1 - p_e} = 1 - \frac{1 - p_o}{1 - p_e},$$

292 Where  $p_o$  = observed agreement among raters, and  $p_e$  = the probability of agreement  
 293 by chance. Agreement could be classed as either slight (0-.20) or fair (.21-.40),

---

<sup>1</sup> We thank the anonymous reviewer for bringing this assessment technique to our attention.

294 though these results would not be considered significant; moderate (.41-.60);  
295 substantial (.61-.80); or near perfect (.81-1) [20].

## 296 **Results**

### 297 **Overall Consumption**

298 Total weights per plate were calculated for each measurement method. Table  
299 A.1 in the Appendix shows these weights in grams, together with provided serving  
300 sizes (provision), in primary and secondary schools, for lunchboxes and school  
301 dinners. It can be seen that, in all categories, children consumed over 80% of the  
302 provided food.

303 Three factors were analysed for differences in food provision and food  
304 consumption: school, lunch type, and gender. There were no differences, except that  
305 children in the primary school were provided with lunchbox meals of a greater total  
306 weight than their secondary school counterparts ( $U = 1686, p = .008, r = -.23$ ).

307 Bland-Altman analyses, presented in Figure 1 and in Table 1, show that the  
308 bias resulting from the digital image capture method was small considering total  
309 consumption for each of the schools and for each type of lunch; standard error (SE)  
310 varied from 0.53% to 2.44% of the mean. Low values for RMSE (12.72) and RRSE  
311 (10.60) indicate less bias and greater accuracy (89.40%) in the modelling of the data.

312

313

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314

Insert Figure 1 about here

315

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### 316 **Consumption of Foods in Each Category**

317 Descriptive statistics for foods consumed in each category, based on weight  
318 measurements, can be found in Table A.2 in the Appendix.

319 The results of the Bland-Altman analysis, shown in Figure 2 and Table A.3 in  
320 the Appendix, indicate that the estimated consumption of food items derived from  
321 digital images presented an acceptably small bias for all categories, with SE ranging  
322 from 1.05% to 2.05% of the mean.

323 However, PRE statistic value for the Fruit and Vegetable subcategory was  
324 10.55%, showing lower accuracy than the others. Similarly, a one sample t-test  
325 identified a significant difference between the two measures for the category of Fruit  
326 and Vegetables ( $t_{(323)} = 2.893, p = .004$ ), but no significant difference between the  
327 measures for all other categories. This result reflects a comparably higher variation in  
328 Fruit and Vegetable serving sizes. Although cafeteria staff were requested to serve  
329 standardised portions this did not always happen, leading to some disparities between  
330 the pre-consumption estimated weights and the actual weights of the portions served  
331 and, consequently, to less accurate consumption estimates, similar to those reported in  
332 other research [21]. While our (well powered) analyses registered this effect as  
333 significant, the actual differences were very small: The average consumed portion  
334 weighed 47.91 grams and this was overestimated via image capture by 1.64 grams  
335 (3.42%) on average.

336

337

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338

Insert Figure 2 about here

339

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340

### 341 **Inter-Rater Agreement**

342 For the full sample, a substantial level of agreement was achieved (Cohen's  $\kappa$   
343 = .679,  $CI = .64 - .72$ ). Categories of Main Starch ( $\kappa = .581$ ,  $CI = .50 - .66$ ) and Fruit  
344 and Vegetables ( $\kappa = .535$ ,  $CI = .46 - .62$ ) achieved moderate agreement; substantial  
345 agreement was achieved for Meat, Dairy, and Wet Foods ( $\kappa = .781$ ,  $CI = .71 - .85$ );  
346 and near perfect agreement was achieved for Snack items ( $\kappa = .819$ ,  $CI = .76 - .88$ ).  
347 The percentage agreement achieved for each category is typical of that previously  
348 accepted in key studies utilising digital image capture [17; 11]. The breakdown shown  
349 in Table A.4 (see Appendix) confirms that coding disparities, where recorded, were  
350 seldom large for any of the categories.

351

## Discussion

352 This investigation supports the use of digital image capture as a valid method  
353 of data collection for free-living research in busy school dining environments. We  
354 have found that estimates derived from digital images can be equivalent to weighed  
355 measures for most food types, and that a high level of inter-rater agreement can be  
356 achieved using the present protocol. This has significant implications for the  
357 collection of nutritional data in children.

358 The current study extends the findings of previous investigations in several  
359 important ways. Whilst a digital image-capture method has been validated for use  
360 with sandwiches brought from home in a contrived study [12], the use of digital  
361 image capture has never before been shown to be accurate for lunchboxes in a real-  
362 life setting. By testing the validity of the digital image capture method against  
363 weighed measures for items brought from home and consumed in a school cafeteria,  
364 this investigation provides evidence that digital images can also enable valid estimates  
365 in this context. This finding should be of interest to researchers measuring children's  
366 consumption in the countries where parental lunch provision is the norm (e.g. Canada;

367 Norway; Ireland), and those where a mixed supply is used (e.g. UK; Australia).  
368 Further, previous investigations conducted in a real-life setting have focused on  
369 younger, primary school age children [17], whilst the current study supports the use of  
370 our digital image-capture method in both primary and secondary school settings.

371 The present paper also presents a more accurate measure of consumption than  
372 the previously published research. By utilising an 11-point scale (0-100% consumed  
373 in 10% increments), rather than continuous unbounded estimation in grams, the  
374 digital image capture measure of the present study yielded greater alignment with the  
375 weighed measure than has previously been achieved in research with children [17].  
376 We consider that continuous weight estimation from digital images may have led the  
377 researchers to adopt comparably lenient criteria. For example, +/-25% weight  
378 discrepancies between the two measures were considered as ‘acceptable agreement’  
379 in one recent validation study [17], where the authors reported pre-consumption  
380 measures and plate waste measures separately, further inflating the number of  
381 agreements. By contrast, we used a measure of consumption for each meal, which is  
382 the variable of most interest to researchers.

383 The present method combined accuracy comparable to the weighed measures  
384 with the convenience of unobtrusive group data collection, avoiding some of the  
385 problems of other commonly used methods [22]. We acknowledge that accurate  
386 visual estimation of consumption is clearly a more complex skill to master than direct  
387 recording of food weights. Nevertheless, we have found that a modest amount of  
388 training (see Method) sufficed to produce reliable coding of a large number of food  
389 types.

390 Based on pilot work, our protocol addressed procedural challenges common to  
391 free-living investigations. For example, we carefully positioned the researchers and

392 recording equipment to minimise disruption but maximise visibility and children's  
393 compliance with measurements, reducing attrition to one or two participants per day  
394 and thereby ensuring that any data loss would have a negligible impact on overall  
395 results. We adjusted our data collection methods to suit two very different cafeteria  
396 settings – a small school (200 students) in a rural area with a strictly regimented  
397 lunchtime routine and a large school (2000 students) in an urban area with a more  
398 relaxed approach to the lunch period. We examined different lunch types, including  
399 lunchboxes brought from home and school dinner meals in the analysis, and recorded  
400 consumption from children with ages spanning 5 to 18 years old. The success in two  
401 very different settings, lunch types, and age groups supports the generalisability and  
402 ecological validity of the digital image-capture method described in the present paper.

403         The present study has significant implications for public health. There has  
404 been a growing interest in the promotion of healthful behaviours in education settings  
405 [23, 24]; with children in the UK consuming around 30% of their daily nutrients at  
406 school [25], the regulation of food eaten in schools has a significant impact on overall  
407 dietary behaviour [26]. Indeed, research has indicated that eating patterns at school  
408 are reflective of typical eating behaviour [27, 28]. With the availability of a valid  
409 measure to collect nutritional data, comparable to weighed measures from a large  
410 sample of school children in-situ, research may now be designed to run an  
411 appropriately powered analysis of what is currently being *consumed* by children at  
412 lunchtime (as we know that lunchtime provision does not equal consumption). An  
413 understanding of what is being consumed will also highlight areas for improvement,  
414 and interventions can be designed (and analysed for effectiveness using the digital  
415 image-capture method) that fulfil these nutritional deficiencies. Such research ought  
416 to then inform policy which will, in turn, be expected to have a significant impact on  
417 children's dietary behaviour and overall health [26].

418           Regarding the digital image capture method, we acknowledge that visually  
419 estimating food item consumption will always be vulnerable to human error; using  
420 this measure we may only estimate the percentage consumed of observed volumes,  
421 and in the absence of true weights for each food item being recorded before  
422 consumption, that this cannot be truly “converted” to a true weight. The present study  
423 does not pertain to suggest that digital image capture will fully replace the gold  
424 standard of weighing every food item before or after consumption, but simply that  
425 with a reasonably sensitive measure, capable of yielding large quantities of data in a  
426 short period of time, that more research regarding children’s diets and lunchtime  
427 consumption may be conducted to observe important trends in children’s eating  
428 behaviour.

429           Some compromises had to be made regarding study design. Considering the  
430 school lunches, estimate weights for each food item available in the cafeteria were  
431 based on the average of five 'typical' servings. These estimates were used in lieu of  
432 weighing each portion before the participants ate their lunch. This commonly used  
433 method [15] was efficient and unobtrusive; it preserved the ‘real-life’ nature of the  
434 investigation and prevented the food from cooling down before the children ate it,  
435 which would have made it less appetising. Nevertheless, it had its drawbacks.  
436 Although cafeteria staff were requested to provide all participants with equally sized  
437 servings, this did not always happen. Unlike foods like fish or bread that were well  
438 standardised (e.g. one fillet or one slice), spoonfuls of vegetables sometimes varied in  
439 size, leading to a disparity between the estimated and actual servings and introducing  
440 a source of noise into the dataset. This barrier to reliability has been previously  
441 identified in associated research [29]. Even though we recorded a significant  
442 difference between data collection methods, a comparably high bias, and greater PRE  
443 for Fruit and Vegetable food category, the actual overestimation was less than a

444 couple of grams on average. This is much less than discrepancies reported in other  
445 studies [17], and unlikely to adversely impact measurement. Our ongoing research in  
446 schools confirms that this method is sensitive enough to detect small changes in  
447 children's fruit and vegetable consumption over time.

448         Due to the fast-paced nature of the school lunchtime environment, it was not  
449 possible to weigh each food item twice and so visual estimations of consumption were  
450 only validated against a single measure, without provision of inter-rater reliability.  
451 However, it is unlikely that measurement was inaccurate. The digital scales used were  
452 correctly set up and tested every morning prior to data collection.

453         Further, a relatively small sample size was utilised. As stated, we used two  
454 schools that differed on several important aspects (age range, setting etc.) in order to  
455 promote generalisability, though we do acknowledge that a sample of just two schools  
456 does limit generalisability. Future research may benefit from exploring the application  
457 of the digital image capture measure in a greater variety of school-based settings,  
458 however, we consider the present sample to indicate the potential for the wide  
459 applicability of the method.

460         Overall, we found the lunchtime provision and consumption to be matched  
461 across study settings, ages, lunch types, and genders. Somewhat counter-intuitively,  
462 children in primary schools brought more food in their lunchboxes than did their older  
463 counterparts. We considered by whom the food was being provided and concluded  
464 that the child's lunchbox was more likely to be prepared by the parents at primary and  
465 by the children at secondary school age. Adolescents may have been less motivated to  
466 pack a substantial lunch and forego quantity and quality for ease, resulting in fewer  
467 food items. The finding that serving sizes were not related to children's nutritional

468 needs indicated that more attention should be given to providing appropriate portions  
469 as children grow and develop [30].

## 470 **Conclusion**

471 This study presented a simple and versatile digital image-capture method for  
472 estimating lunchtime consumption of children in schools. We obtained a high  
473 agreement with the weighed measures and good inter-rater reliability using total  
474 consumption and food category scores, derived from the weight estimates of  
475 individual food items. These data can be used to calculate the energy content of  
476 children's meals and their micro- and macro-nutrient composition, using published  
477 nutrition tables and school meal recipes, to provide more detailed measures of  
478 consumption and its changes over time, for example in studies that seek to evaluate  
479 the effects of various school-based interventions [xxx et al.; unpublished results in  
480 submission].

481

## 482 **Declarations**

483 **Xxx**

484 Submitted separately

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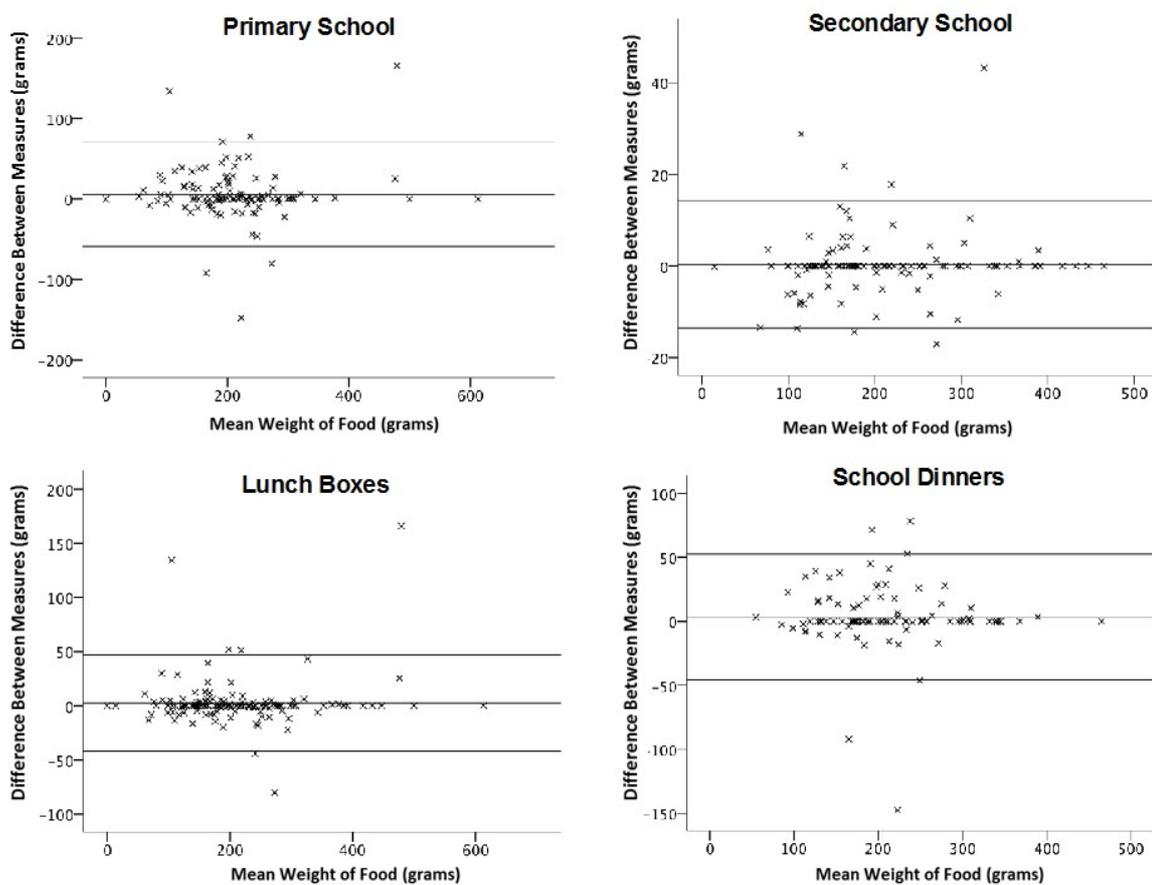
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### Figures

574 *Figure 1.* Bland-Altman plots comparing consumption estimates (in grams) made  
575 from digital photographs and weighed measures by each school and meal type.

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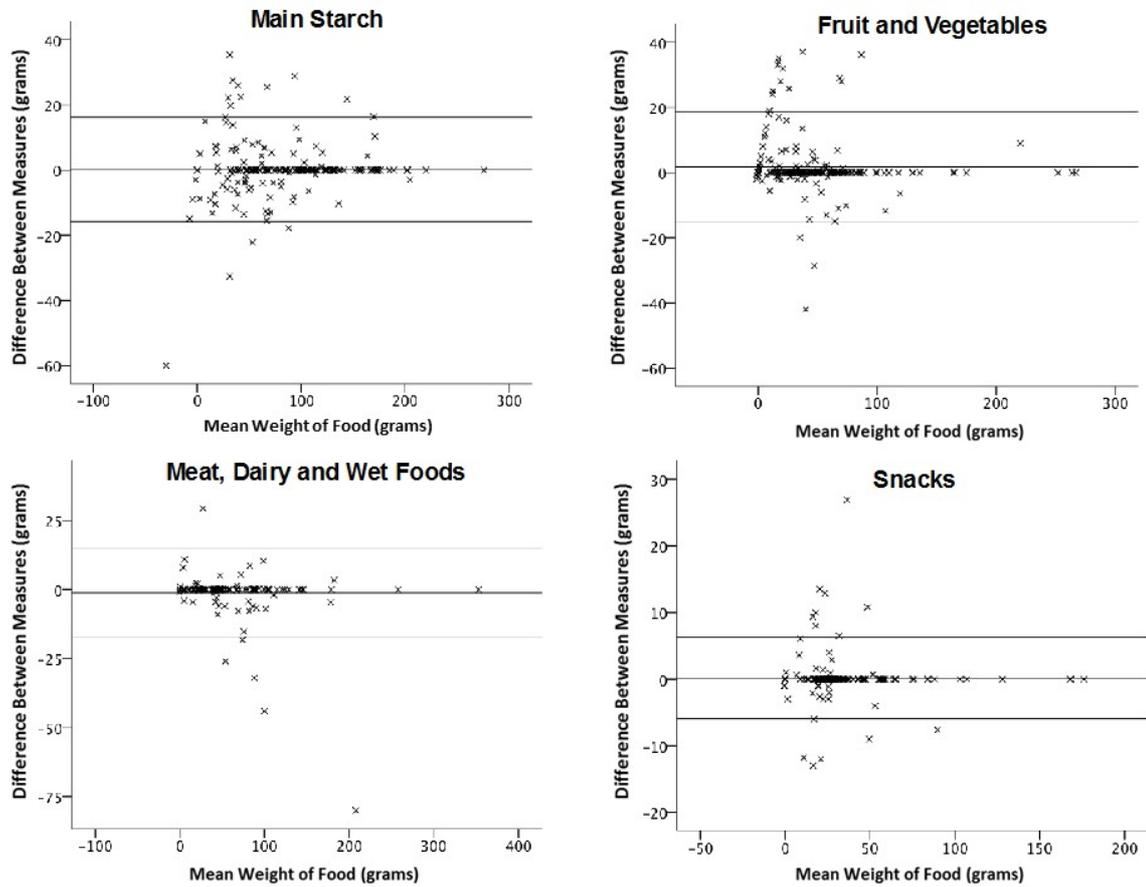


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579 Figure 2. Bland-Altman plots comparing consumption estimates (in grams) made  
 580 from digital photographs and objective weighed measures by category.

581



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584

Table 1.

585

*Bland-Altman analysis results for all meals (in grams) classified by school*

586

*and lunch type.*

587

		N	Bias	SD of Bias	Limits of Agreement		PRE
School	Primary	116	5.86	32.92	-58.66	70.38	2.25
	Secondary	123	.36	7.07	-13.5	14.22	-.09
Lunch	Lunchbox	137	2.67	22.60	-41.63	46.97	.96
	School Dinner	102	3.52	24.98	-45.44	52.48	1.14

588

589

**Appendix.**

590

*Table A.1.*

591

*Provided and consumed food in grams for the lunches in each school and*

592

*meal type.*

	Primary school				Secondary school			
	Lunch Box		School Dinner		Lunch Box		School Dinner	
	M	SD	M	SD	M	SD	M	SD
Provided	283	107	253	60	247	118	240	106
Consumed	229	110	204	64	199	93	223	87

593

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596

*Table A.2.*

597

*Provision and consumption in grams for four food categories.*

598

	Number of Portions				Provided (Grams)		Consumed (Grams)	
	Primary		Secondary		M	SD	M	SD
	Lunch Box	School Dinner	Lunch Box	School Dinner				
Main Starch	54	84	65	43	101.54	47.84	84.96	51.10
Fruit and Vegetables	62	68	98	5	66.39	45.26	47.91	41.51
Meat, Dairy and Wet	4	63	27	22	65.39	51.5	57.51	45.37
Snacks	100	42	64	27	37.44	25.92	33.42	26.82

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602

*Table A.3.*

603

*Bland-Altman analysis results for the four food categories.*

604

Category	N	Bias	SD of Bias	Limits of Agreement	SE of 95% CI	PRE
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Main Starch	246	0.22	8.19	-16.03	16.27	0.90	3.04
Fruit and Vegetables	233	1.64	8.67	-15.35	18.63	0.98	10.55
Meat, Dairy and Wet	186	-1.14	8.12	-17.06	14.78	1.03	0.16
Snacks	233	0.15	3.12	-5.97	6.27	0.35	1.12

605

606

607

*Table A.4.*

608

*Percentages of inter-rater agreement and disparities for the four categories.*

609

Category	Full Agreement	10% Disparity	20% Disparity	> 20% Disparity
Main Starch	81.00	7.60	2.50	8.90
Fruit and Vegetables	83.60	11.00	2.70	2.7
Meat, Dairy and Wet	95.20	4.80	-	-
Snacks	94.10	2.90	1.50	1.50

610