Does children's energy intake at one meal influence their intake at subsequent meals? Or do we just think it does?

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Summary

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It is widely believed that young children are able to adjust their energy intake across successive meals to compensate for higher or lower intakes at a given meal. This conclusion is based on past observations that although children's intake at individual meals is highly variable, total daily intakes are relatively constant. We investigated how much of this reduction in variability could be explained by the statistical phenomenon of the variability of individual components (each meal) always being relatively larger than the variability of their sum (total daily intake), independent of any physiological compensatory mechanism. We calculated, theoretically and by simulation, how variable a child's daily intake would be if there was no correlation between intakes at individual meals. We simulated groups of children with meal/snack intakes and variability in meal/snack intakes based on previously published values. Most importantly, we assumed that there was no correlation between intakes on successive meals.

In both approaches, the coefficient of variation of the daily intakes was roughly 15%, considerably less than the 34% for individual meals. Thus, most of the reduction in variability found in past studies was explained without positing strong 'compensation'. Although children's daily energy intakes are indeed considerably less variable than their individual components, this phenomenon was observed even when intakes at each meal were simulated to be totally independent. We conclude that the commonly held belief that young children have a strong physiological compensatory mechanism to adjust intake at one meal based on intake at prior meals is likely to be based on flawed statistical reasoning.

Keywords: *diet*, *energy intake*, *variability*, *appetite regulation*.

Introduction

Parents often ask why their young children eat so erratically, sometimes 'like a bird' and at other times 'like a horse'. The classic observations made by Clara Davis in the 1930s on the dietary intake patterns of healthy institutionalised infants who were allowed to select their own diets for several months are often used to reassure these parents.[1,2] Despite the fact that 'tastes changed unpredictably from time to time, refusing as we say "to stay put," while meals . . . would have been a dietitian's nightmare',[2] [p. 260] it was observed that they grew well and were healthy; Davis postulated 'the

existence of some innate, automatic mechanism for its accomplishment'.[2] [p. 260]

Subsequent researchers, who fixed the food volume of first courses and varied the energy content of a second course, have noted that energy intake on a second *course* was higher after the low energy than after the high energy first *course*, suggesting that young children can modify their intake in response to the energy intake of the diet.[3,4]

Other studies have attempted to assess whether children's energy intake at one *meal* influences their intake at subsequent *meals*. One of the most highly cited

publications is a New England Journal of Medicine study by Birch and colleagues of the food intake of children attending day care.[5] The researchers measured 15 children's food intake at each of six meals (breakfast, lunch, dinner and morning, afternoon and evening snacks) for each of 6 days (two consecutive days in each of three consecutive weeks). Child-specific coefficients of variation [CV, calculated as the standard deviation (SD) divided by the mean] were calculated for each meal and for total daily energy intake, making it possible to compare the variability of meals, snacks and total daily intakes with different mean values.

They found that whereas the children's meal-specific intakes were highly variable across the 6 days, total daily intake was relatively constant for each child. The average CV for a child's energy intake at individual meals was 33.6%; in contrast, the average CV for each child's total daily intake was only 10.4%. In most cases, high energy intake at one meal was followed by low energy intake at the next meal, and vice versa (Table 1). Moreover, the pattern of relatively constant total daily intakes (i.e. small within-subject CVs) was evident whether the data on intake were analysed according to calendar day or according to 24-hour periods that included parts of 2 days and an overnight fast. These observations, that although children's food consumption is highly variable from meal to meal, daily intake is relatively constant, led the authors to conclude that children 'adjust their energy intake at successive meals'.

A subsequent study gathered data from mothers on dietary intake of children living in their everyday environment.[6] Twenty-four-hour recalls were administered on seven occasions to the mothers of 181 preschool children. Again, each 24-hour period was divided into six meals or snacks. CVs for energy consumption at the six eating occasions ranged from 46.5% to 165.8%, compared with 30.3% for the whole day. The CV for the observed whole-day energy consumption was significantly less ($P < 0.001$) than would be expected if no self-regulation of energy intake (no meal-to-meal correlation) occurred. As these findings in children living in their everyday environment were consistent with observations under more controlled study conditions, the authors concluded that – in the short term at least – children who eat less at one meal compensate at another.

Based on the evidence of such studies, it now appears to be widely believed that young children have the physiological ability to compensate for high intake at one meal with low intake at the next, and vice versa. The 2008 Position of the American Dietetic Association on 'Nutrition Guidance for Healthy Children Ages 2–11 Years', for example, states that '. . . children are able to adjust their food intake across successive meals to regulate energy intake for 24-hour periods . . .' [7] [p. 1043], quoting Birch and colleagues' study[5] to support this statement.

But is the lower CV for daily intakes than for individual meal intakes really evidence of such 'compensation'? Or could these results instead be explained by the statistical phenomenon that the variability of individual components (each meal) will always be relatively larger than the variability of their sum (total daily intake)?[8] We wondered how much of the reduced CVs could be explained by this phenomenon, independent of any postulated 'compensating mechanism'. What would be the CVs for each meal and total daily intake if a child had no meal-to-meal physiological 'memory' and behaved at each meal independently of whether the intake at the previous meal was above or below average?

Methods

Our calculations were of two forms, one based on computer simulations of intakes at individual meals, the other based on theoretical formulae for variability of sums or totals as a function of the variability of their components. We explicitly built into the simulations and calculations that there be no correlation between successive components (meals).

Simulated data

We used a random number generator in the statistical package STATA (version 10.0, StataCorp, College

Table 1. Results of Birch and colleagues' study of variability in energy intake among day care children[5]

Parameter	Value
CV for individual meals	33.6%
CV for total daily intake	10.4%
Total number of meal-to-meal negative correlations in study group (of a possible 75)	48
Correlation between number of meal-to-meal negative correlations per child and child's CV for total daily intake	−0.51

CV, coefficient of variation.

Table 2. Parameters for simulations and theoretical calculations

Meal	Mean[a]	SD[a]	CV
Breakfast	250	84.0	33.6%
Morning snack	150	50.4	33.6%
Lunch	300	100.8	33.6%
Afternoon snack	150	50.4	33.6%
Dinner	500	168.0	33.6%
Evening snack	150	50.4	33.6%
Total for day	1500		

[a]Means and SDs are in kcal.
SD, standard deviation; CV, coefficient of variation.

Station, TX, USA) to generate a dataset of 540 observations, corresponding to the intakes for 6 meals per day for 6 days for 15 children. The intake of a child at a particular meal on a particular day was drawn at random from a standard normal distribution with a mean and SD that depended only on the type of meal. Table 2 shows the means and SDs for the main simulations and theoretical calculations. The CV of 33.6% was chosen to match the average CV observed in the study of Birch and colleagues.[5]

Thus, for example, for each child, the child's intakes at breakfast on the six different days were drawn independently of each other from a standard normal distribution with mean of 250 and SD of 84. Likewise, the child's intakes at mid-morning snack for the 6 days were drawn independently of each other from a standard normal distribution with mean of 150 and SD of 50.4, and so on for each of the different types of meal. Most importantly, for each child, the intakes at one type of meal were drawn independently of the intakes at each other type of meal. As we were interested solely in intra-child variations, we assumed, without any loss of generality, that the means were the same for each of the 15 children.

From these 36 observations on each of 15 children, we repeated the same statistical analyses as in the study of Birch and colleagues.[5] First, for each child, we calculated and graphed the CV for energy intake for each child at individual meals, as well as for total daily energy intake, thereby obtaining 7 CVs per child. Note that each CV summarises the variation across 6 days. For each type of meal, as well as for the daily intake, we also averaged the CVs over the 15 children, thereby obtaining one 'average' CV for each meal and one CV for daily intake. Corresponding CVs were also calculated for five additional 24-hour periods (e.g. from lunch one day to mid-morning snack the next).

Second, for each child, we calculated the correlations between intake at a given meal and intake at the next meal on the same day. This produced 5 such correlations per child, beginning with the correlation between intake at breakfast and mid-morning snack, and ending with the correlation between intake at dinner and evening snack. A negative correlation means that higher than average intakes at one meal were followed by lower than average intakes at the next meal that day, and vice versa. The 75 correlations (5 correlations per child times 15 children) were examined and the number that were negative was tallied. Finally, for each child, the number of negative correlations (out of a maximum of 5) was taken as an index of 'compensation'. We then calculated the correlation (over the 15 children) between the child's compensation index and the child's CV in total daily energy intake.

Most of the results are reported below for just one dataset consisting of 15 children. However, to avoid the possibility that the results obtained from this one simulated dataset were unrepresentative, we repeated these analyses on a total of 400 randomly generated datasets of 15 children each.

In order to examine how the CVs for total daily energy intakes would differ from the component CVs of the individual meals if there *were* serial meal-to-meal correlations, we repeated our simulations with datasets containing serial (negative) correlations of $r = -0.1$, -0.2, -0.4 and -0.6 between successive meals/snacks. The meals/snacks were simulated by sampling from a multivariable standard normal distribution with a correlation matrix specifying the desired degree of negative correlation between successive meals (and no correlation between non-successive meals). Values were then unstandardised to obtain meals/snacks with the means, SDs and CV for individual meals specified in Table 2. We repeated our analyses (calculation of total meal CVs, number of negative meal-to-meal correlations, correlation between number of meal-to-meal correlations and total daily CV) to allow comparison with the results of Birch[5] and our results from the dataset specifying zero correlation.

Theoretical calculations

We also calculated the CVs one would expect to see from day to day in the total daily intake if the daily variations about the mean for one meal were independent of the variations around the mean for each of the other meals. We did this using the means and SDs in
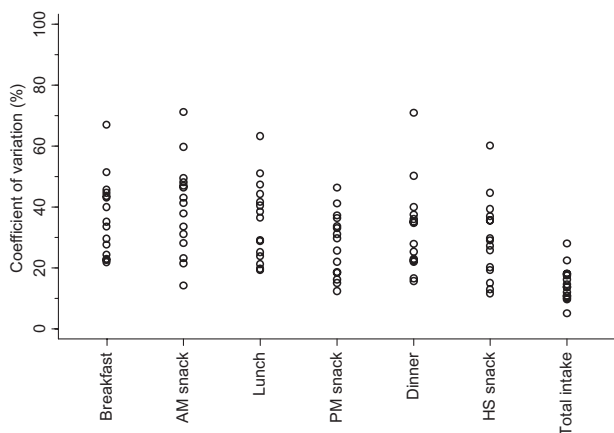
Figure 1. CV for total energy intake and for intake at the six meals and snacks for individual children (within-subject variation), obtained from data simulated to have no meal-to-meal correlation. Each point represents the CV for a single child over 6 days. CV, coefficient of variation; AM, morning; PM, afternoon; HS, evening.

Table 1, and invoking the statistical fact that the variance of a sum of uncorrelated components is the sum of the variances of the individual components. We then converted the variances to SDs and divided them by the mean of the total to obtain a CV for the total. The formulae are given in the Appendix. We repeated the calculations using different partitions of the mean of 1500 calories per day, such as equal means of 250 calories per meal rather than those shown above.

Results

Simulated data

Variability in energy intake within children

The CVs for each of the 15 children for each of the six individual meals and for the total intake are shown in Fig. 1. As they were drawn from distributions having a 33.6% CV, it is not surprising that the observed CVs for individual meals average about 34%. In contrast, the within-subject CV for total daily energy intake was only 13.9% on average, despite the fact that we did not build serial negative correlation into the intakes from successive meals. The lowest and highest CVs for total daily intake seen across the 400 datasets were 10.7% and 19.3%, respectively, with a median of 15.4%.

Serial correlations

Some 34, close to (the expected) half, of the 75 correlations between intakes at pairs of successive meals on

the same day in the same child were negative. When repeated 400 times, the number of negative correlations observed ranged from 25 to 50. This compares with 48 negative correlations in the study of Birch and colleagues (Table 1).[5]

Degree of 'compensation' and daily variability

There was an inverse relation between the number of negative meal-to-meal correlations per child and the child's CV for total energy intake (Pearson $r = -0.18$; two-sided $P = 0.52$). The extent of the relationships, calculated in the same manner, over all 400 datasets generated is shown in Fig. 2, where the average $r = -0.28$ and 80% of the r's were between -0.59 and 0.04. The value of -0.51, the finding of Birch and colleagues (Table 1),[5] is on the 18th percentile of this distribution.

Individual differences in patterns of intake

For all 15 children, the CVs for total daily energy intake were smaller than the CVs for mealtime intake. Figure 3 shows the patterns of intake for three children with the lowest CV (8.2%), the highest CV (23.3%) and the median CV (13.7%) for total daily energy intake. Intakes at each meal were standardised to be expressed as energy Z-scores [i.e. (energy intake at a given meal – child's average intake for that meal)/SD of
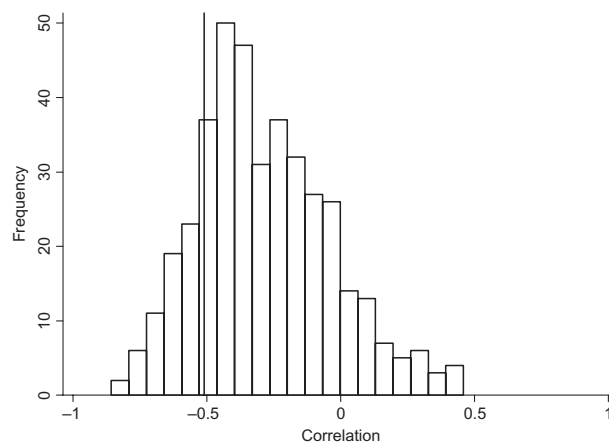

Figure 2. Relationship between degree of 'compensation' and daily variability, as measured by the correlation between the number of negative meal-to-meal correlations per child and the child's coefficient of variation for total energy intake. Each of the 400 data points contributing to the distribution represents the relationship seen in one dataset of 15 children (400 datasets in all). The simulations assumed no within-child correlation between intakes at successive meals. (The vertical line represents the finding of Birch *et al.*[5]).
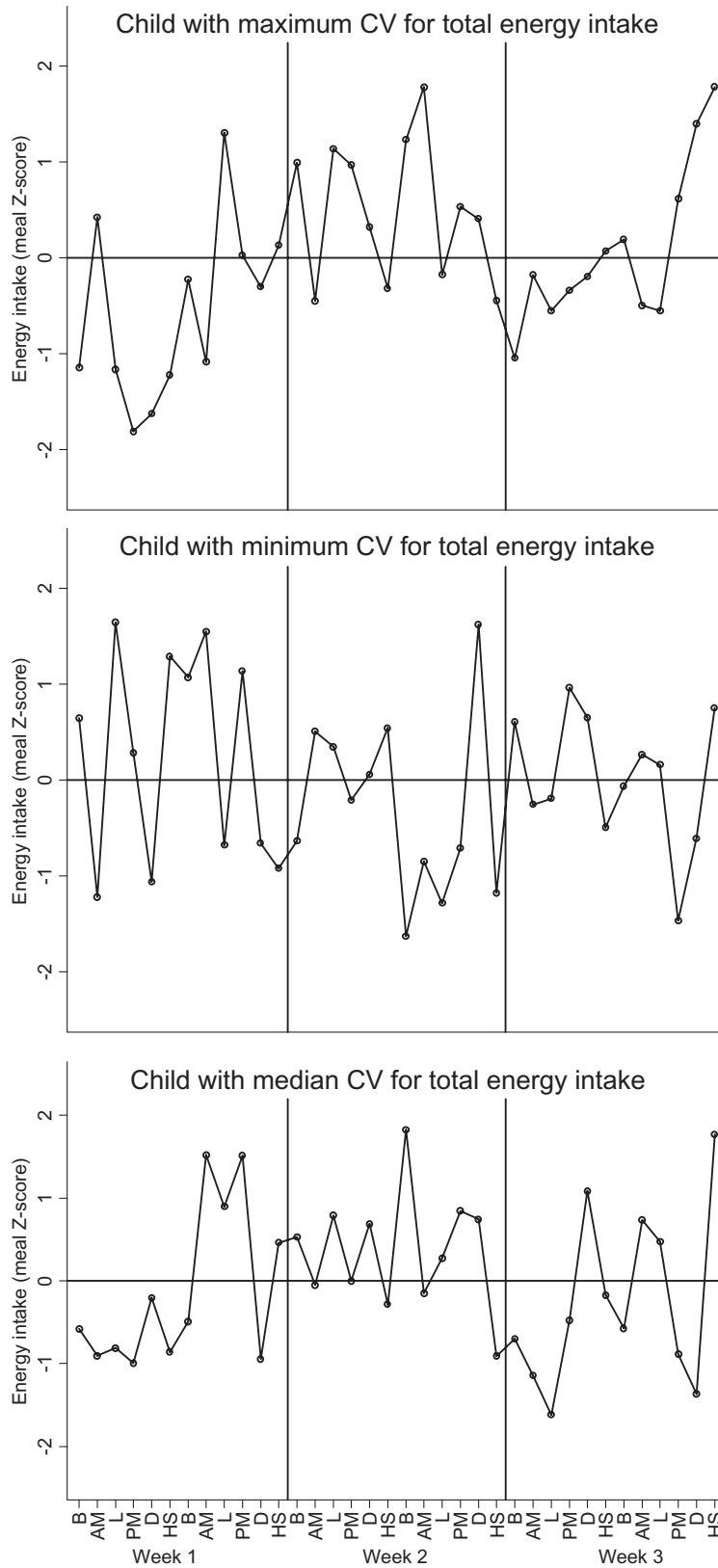
Figure 3. Energy intake at mealtimes for three children with low, high and median CV for total daily energy intake on 2 consecutive days for 3 weeks, obtained from data simulated to have *no* meal-to-meal correlation. CV, coefficient of variation; B, breakfast; AM, morning snack; L, lunch; PM, afternoon snack; D, dinner; HS, evening snack; and vertical lines indicate breaks in successive meals.

child's intake for that meal]. Thus, the horizontal line at 0 represents a child's average intake level for each meal, and Z-scores crossing from above zero to below zero between successive meals would represent a higher than average intake at one meal being followed by a lower than average intake at the subsequent meal (or vice versa). We leave it to the reader to find distinctive profiles for the different children, but urge that they temper their observations of any distinctiveness with the knowledge of how the data were generated.

Period of intake regulation

We also investigated the variation in total energy intake for five different 24-hour periods spanning parts of two successive calendar days. The mean within subject CVs were comparable to those for the calendar day (13.9%) – 13.2%, 13.9%, 14.7%, 13.4% and 14.8%.

Simulation of data with serial meal-to-meal correlation

In Table 3, results from our simulations specifying varying degrees of serial meal-to-meal correlation are shown. As expected, the variability in daily intake, assessed by the mean CV for daily intake, decreased from 13.8% with a serial correlation of −0.1 to 8.7% with a serial correlation of −0.6. The result of Birch, 10.4%, is close to the mean value obtained with a serial correlation of $r = -0.4$, although this value was observed in a dataset with a serial correlation as low as −0.1. The number of meal-to-meal negative correlations in a study group (of a possible 75) increased with increasing degree of serial correlation from 44 ($r = -0.1$) to 69 ($r = -0.6$). The value of 48 observed by Birch cor-

responds to a serial meal-to-meal correlation lower than −0.2. The inverse relationship between 'compensation' (number of negative meal-to-meal correlations) and daily intake variability became weaker with increasing negative meal-to-meal correlation, and the result of Birch was not compatible (<1st percentile of distribution) with our datasets generated with serial correlations stronger than −0.2.

Theoretical calculations

We calculated the CV of the total daily intakes by substituting the parameters in Table 1 into equation 4 (shown in the Appendix). The CV of 15.4% obtained was in excellent agreement with the results of our simulation study. Both are not that much larger than the 10.4% seen in the actual study of Birch and colleagues. When we altered the input parameters to allow for other patterns in the means or in the SDs, the results of both the theoretical calculations and simulation results were only slightly lower than 15%. They all suggest that even in the absence of any negative within-child correlation between intakes at successive meals, the CVs for total daily intakes will be less than half of those seen for individual meals.

Discussion

By both simulations and theoretical calculations, we have quantified how – even without any in-built serial correlation – the CV for total daily intake (approximately 15%, depending on the input parameters) is considerably smaller than that for individual meals (33.6%). Thus, the observed CV for total daily intake of

Table 3. Comparisons between simulated datasets with varying degrees of serial meal-to-meal correlations

	Simulated negative meal-to-meal correlations (r)				
	0	−0.1	−0.2	−0.4	−0.6
Mean CV for total daily intake[a]	15.3%	13.8%	12.8%	10.6%	8.7%
Minimum mean CV for daily intake produced in 400 datasets generated	10.7%	10.0%	9.4%	8.2%	6.5%
Number of meal-to-meal negative correlations in study group (of a possible 75)[a]	38	44	50	61	69
Correlation between total number of negative meal-to-meal correlations above with mean daily CV (r)	−0.28	−0.19	−0.10	0.11	0.26
Percentile of distribution of correlation between total number of negative meal-to-meal correlations per child and child's mean daily CV that Birch's result of −0.51 corresponds to	18	11	6	<1	<1

[a]Mean of 400 datasets.
CV, coefficient of variation.

10.4% in the actual study of children cannot be taken as evidence for strong biological 'compensation', as much of the reduction from 33.6% can easily be accounted for with zero correlations between intakes at successive meals. As the 10.4% seen with real children[5] was slightly lower than we were able to produce in any of the 400 datasets we generated (10.7%), one might infer that there may be a small amount of physiological compensation in addition to the much larger statistical effect of aggregation of unrelated components. The small sample sizes (15 children, 6 days) in the study of Birch make it difficult to conclusively establish the degree of serial meal-to-meal correlation associated with their study results; nevertheless, from our simulations of datasets with a known degree of serial correlation it appears most likely to be compatible with a correlation no stronger than –0.4, possibly in the range of –0.2 or –0.3. Although rules of thumb with respect to interpretation of correlation coefficients vary, this degree of correlation would generally be considered weak-moderate, explaining at most 20% of the variability in young children's energy intake.

Birch and colleagues had also noted that children in their study with the smallest CVs for total daily energy intake had the strongest evidence of meal-to-meal compensation in energy intake.[5] This pattern, quantified as a correlation of –0.51 and an attached P-value of <0.05, was taken as providing support for the view that the relatively small CVs for total energy intake were due in part to compensation in energy intake at successive meals. However, without any built-in serial correlations, we also were able to find negative correlations in a large majority of the datasets we generated. The explanation for this is that smaller CVs for the daily totals coupled with a large number of serial 'compensations' within each day are two expressions of the same phenomenon, even if the 'compensations' are not biological but purely random. Thus, it is not appropriate to test whether the observed correlation of –0.51 observed in the children is significantly different from *zero*, but rather different from what one would expect under a model with no serial correlation. Using as a reference the histogram in Fig. 1, with –0.28 as its centre, and allowing for the possibility of dataset to dataset variation, we see that the –0.51 in the 15 actual children is no longer statistically significant (it is at the 18th percentile in Fig. 1). Although the contribution of random variability in the observed variability of children's energy intake has been questioned in the past,[8] our study is the first to provide empirical evidence to support this speculation by the use of simulation, where the degree of correlation in the data is pre-specified.

The statistical phenomenon exhibited here, that the CV of a total is smaller than that of its individual components, is an intuitive one. After all, our daily lives are governed by this law of cancellation of extremes when several uncorrelated quantities are added together. For example, while the daily earnings of a physician working on a fee-for-service basis may vary considerably from day to day (depending on the day's patient case mix or other factors), their annual earnings will be reasonably stable from year to year. We would prefer to act as our own insurance for a set of six independent pieces of computer equipment than we would for just one; insurance companies carry this principle much further and use portfolios not of 6 but of 6 million clients, again relying on the stability, or reduced variability or uncertainty that comes from the aggregation of individually quite unpredictable (but thankfully quite uncorrelated) behaviours.

The results of this study have important implications for our understanding of children's energy intake. Although the results of Birch and colleagues continue to be widely cited (over 130 Web of Science citations at the time of manuscript submission, as well as citations in guidelines of the American Dietetic Association[7] and the American Academy of Pediatrics' Pediatric Nutrition Handbook[9]), our study has demonstrated that young children probably do *not* in fact have a strong physiological compensatory mechanism to regulate meal-to-meal intake. Other factors, such as the amount of food served[10] or parental behaviour,[11,12] may instead be more important in determining intakes. Alternatively, it is possible that self-regulation of intake in young children is not best assessed through meal-to-meal regulation, but rather through regulation of day-to-day intakes or of intakes early in the day vs. intakes later in the day. In the light of the current epidemic of paediatric obesity,[13] a correct understanding of energy regulation (and in turn, possible causes of dysregulation) is important to ensure that efforts to promote optimal energy intake among young children are targeted appropriately.

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Appendix

We show how the coefficient of variation (CV) of a total daily intake is related to the CV of its component intakes, assuming that these successive components are uncorrelated.

The CV of a variable is the standard deviation, which we will denote by SD, as a fraction or percentage of the average or mean (μ):

$$CV = \frac{SD}{\mu}(fraction) \quad \text{or} \quad = \frac{SD}{\mu} \times 100 \, (\%)$$

It will help to reverse this definition, writing the SD as a function of μ and CV, namely

$$SD = \mu \times CV \tag{1}$$

We denote the intakes from the six meals and snacks consumed in a day by $I_1, I_2, \ldots, I_6$, and their total by T, so that

$$T = I_1 + I_2 + \ldots + I_6$$

We denote the means for I_1 to I_6 by μ_1 to μ_6 and their SDs by SD_1 to SD_6.

The CV of T is the SD of T (denoted by SD_T), as a fraction of the average of T, or μ_T:

$$CV_T = 100 \times \frac{SD_T}{\mu_T} \%$$

Regardless of any correlations among the I's, the denominator of the desired CV, the average total daily intake, is simply the sum of the meal-specific averages, i.e.

$$\mu_T = \mu_1 + \mu_2 + \ldots + \mu_6$$

If the I's are uncorrelated, then the numerator of the desired CV, the SD of T is obtained as the square root of the sum of the squares of the meal specific SDs, i.e.

$$SD_T = \sqrt{SD_1^2 + SD_2^2 + \ldots + SD_6^2} \tag{2}$$

Now, replacing each SD in (2) by its equivalent from (1), we obtain:

$$SD_T = \sqrt{CV_1^2 \times \mu_1^2 + CV_2^2 \times \mu_2^2 + \ldots + CV_6^2 \times \mu_6^2} \tag{3}$$

giving the general equation:

$$CV_T = \frac{\sqrt{CV_1^2 \times \mu_1^2 + CV_2^2 \times \mu_2^2 + \ldots + CV_6^2 \times \mu_6^2}}{\mu_1 + \mu_2 + \ldots + \mu_6} \tag{4}$$

If the CVs for each of the six meals are equal, the expression for CV_T simplifies to:

$$CV_T = \frac{CV_{meal}}{\sqrt{6}} \times \frac{\sqrt{average\ of\ \mu_1^2\ to\ \mu_6^2}}{average\ of\ \mu_1\ to\ \mu_6} \tag{4*}$$

If in addition, the μ's for the six meals are assumed equal, CV_T simplifies further to

$$CV_T = \frac{CV_{meal}}{\sqrt{6}} \tag{4**}$$