Title: Short term weight variability in infants and toddlers: an observational study

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ABSTRACT

Aims

To explore short-term weight variability in young children; a) how it relates to expected weight gain and b) how it is affected by age, time of day, and dietary intakes and outputs.

Methods

Twenty healthy infants aged 2-10 months and 21 healthy toddlers aged 12-35 months were weighed at home by their parents six times over three days. The toddlers' parents also recorded whether they had eaten, drunk, urinated or passed stool in the previous 2 hours. The primary outcome was "noise": the within-subject weight standard deviation (SD) pooled separately for infants and toddlers, compared to their expected weight gain over 4 or 8 weeks. Analysis by successive pairs of weights was used to assess the extent of short-term weight gain and loss associated with time of day and eating, drinking and excretion.

Results

In infants, noise (117g) was much less than the expected weight gain over 4 weeks (280-1040g) but in toddlers, noise (313g) was higher than the expected gain over 4 weeks (180-230g) and around three quarters the expected gain over 8 weeks (359-476g). In toddlers, weight tended to fall overnight and rise by day, and recent eating and passage of stool were associated with increased weight gain, even after adjustment for time of day.

Conclusions

In toddlers the recorded weight may be 300g higher or lower than the underlying weight trajectory, so that their weight gain based on measurements collected fewer than 8 weeks apart will often be misleading.

What is known about this topic

- Infant weight varies in the short term, but average weight gain over 4 weeks is much larger, making it possible to distinguish between true weight gain (signal) and natural variability (noise).
- The amount of noise in toddlers is not known.

What this study adds

- In toddlers aged 12-36 months noise was much greater and signal much smaller than in infants.
- By age 12 months noise was greater than signal over a 4 week interval.
- In toddlers, weight tended to fall overnight and rise by day and be higher after eating and passage of stool.

How this study might affect research, practice or policy

- Clinicians should aim to weigh toddlers at intervals of not less than 8 weeks.
- Where accurate assessment of weight gain is important, weighing at roughly the same time each day, and not within 2 hours of a meal, will reduce the noise.

INTRODUCTION

The health and nutritional status of infants and preschool children is monitored by weighing them regularly in well baby clinics and at paediatric reviews, and a drop in weight trajectory may be the first indication of underlying problems (1). However, when assessing weight change over time, it is important to understand that this consists of two distinct components: true weight change (the 'signal') and random weight variability which is unrelated to growth ('noise'). In an earlier paper we explored the extent to which this noise could potentially drown out the signal in infants aged under one year (2). As well as a large secondary data analysis, that paper briefly described serial data collected in infants to provide an estimate of noise, but no data were available then for older children.

In the UK most children are weighed routinely up to 12 months of age, and then again at 24 months. However, if there are concerns about their growth or health individual children may be weighed more beyond 12 months and in these children the interpretation of weight gain, loss or stasis is particularly critical. We thus conducted a further study in children aged 1-3 years, replicating the previous methodology (2), and here we combine the two samples, aiming to quantify short-term weight variability in toddlers compared to infants, to assess how it is influenced by feeding and elimination, and to compare it with expected weight gain over 4 and 8 weeks.

METHODS

Recruitment

Social media and a snowball sampling design were used to recruit infants aged 0-36 months with no pre-existing medical conditions living in the Greater Glasgow area. After first contact from interested families, a leaflet with further information was provided. If families consented, they were either visited at home or attended the Human Nutrition department, where the researcher obtained written consent and trained the parent/guardian in the experimental procedure.

Ethical approval (application number 200170123) was given by the University of Glasgow College of Medical, Veterinary and Life Sciences Ethics Committee, first in 2018 and then extended to 26/4/2022.

Procedure

The data for infants (<12 months) were collected by HS and for toddlers (>12 months) by FH-G. At the first meeting on day 1 two weight measurements were collected, one by the researcher and one by the parent/guardian, using a set of portable Seca 345 grade III clinical scales with a precision of ±5g. To prevent bias for the repeated measurements, four standard numbered bags, containing different amounts of rice, were prepared in advance by another researcher. During each measurement one of these bags was placed on the scale beside the child and the total reading and the bag number were recorded. These thus masked both observers to the true weights. Before analysis the code for the bag weights was broken and the weight of the bag used was subtracted from the recorded weight. It was not possible to standardise the time for the first and last meeting and we did not collect intake/excretion data at these times (see later).

The scales were then left with the family for the next 48 hours. They were asked to collect weights at a time in the evening (PM) and morning (AM) when the child was already being undressed or dressed, i.e. four measurements over days 1 to 3. They were advised to place the scales on a level surface, to fully undress their child and, if the child became distressed during weighing, to try again later. Families were provided with slips on which to write each weight with date and time and a sealed cardboard box to post them in, to prevent them comparing successive weights and biasing the results. For the infants, parents reported whether they were breast feeding or not. For the toddlers, parents kept an intake/excretion diary, recording at each weighing whether the child had eaten, drunk, urinated or passed stool in the previous two hours. Later on day 3, the final meeting repeated the process of the first meeting, with the researcher and parent each weighing the child. In this way each parent collected up to six weights spread over 3 days.

Statistical analysis

All statistical analysis was conducted in Microsoft Excel (Version 16.64, 2021) and IBM SPSS (Version 28.0.0.0 (190), 2021. The weight data were first entered per child (wide file) for the new toddler sample combined with the infant data already held. The primary outcome was the average within-subject standard deviation (SD) of weight change (noise) for infants aged 0-12 months and toddlers 12-36 months, using the six parental weights available per child, and excluding the researcher weights:

$$Noise = \sqrt{\sum_{i=1}^{N} \frac{2SD_i^2}{N}}$$

where SD_i is the SD for the ith of N subjects. This formula extends the formula for the technical error of measurement, given by

$$TEM = \sqrt{\sum_{i=1}^{N} \frac{d_i^2}{2N}}$$

where d_i is the difference between two weights for subject *i* measured at the same time. The noise formula handles more than two measurements per subject (3), and includes a factor of √2 to reflect the fact that weight change involves two weights and hence two measurement errors. The average noise for infants and toddlers and different age groups was also calculated the same way. These were compared to the expected weight gain over 4 or 8 weeks by calculating change in median weight in WHO standard over all possible 4- and 8-week intervals from birth to 36 months and averaging the two sexes (see Figure 1). A long file created with one row per pair of successive weights was then used to calculate the outcome of weight change between successive weight pairs. The association with breast feeding (in infants only) was explored using the t-test. The effects of age and time (night = PM to AM, day = AM to PM) were explored using linear regression with an interaction term of age*time. The effects of eating, drinking and excretion on weight gain in the toddlers were tested individually using linear regression, then adjusted for time and mutually adjusted.

RESULTS

Data on 20 infants aged 2-10 months were collected in in May-June 2018 and on 21 toddlers aged 12-35 months in May-June 2021. One toddler family provided four instead of six weights. All the infants had milk feeding information and all but one of the toddlers had a completed diary. Their mean (SD; range) weight z score was -0.02 (0.97; -2.1 to 1.9) and 20 (49%) were girls. Of the infants, all but three had been at least partially breastfed.

The repeated weight measures collected on day 1 and day 3 showed little variability. On day 1, 25 weight pairs (71%) were identical and 95% varied by no more than 40g, with one varying by 60g and one by 220g, in a child who went on to show consistently high weight variability (TEM = 26g). On day 3, 95% were identical and none varied by more than 20g, resulting in a much lower TEM = 4g.

The median within child weight SD was 95g but this varied by individual from 20-500g (see figure 1). The estimates for noise broken down by age group are shown in table 1. Noise in young infants, at 104g was rising to 334g between ages 12-24 months. In toddler noise was far lower than expected weight gain over 4 weeks, but beyond age 12 months it was well above the average expected weight gain over a 4-week period (Table 1, figure 2).

When analysed as weight increments there were 204 weight pairs, 100 for the infants and 104 for the toddlers; 107 pairs spanned overnight and 97 spanned the day. There were no obvious differences in weight change for breast feeding infants compared to those receiving formula or mixed feeding (data not shown). In infants there was no difference in weight change between day and night (mean difference 2g, $P = 0.9$) but in toddlers weight decreased substantially overnight and increased through the day (mean difference 367g, $P < 0.001$). In a combined analysis the slopes of the lines of weight change versus age for night and day were highly significantly different ($P < 0.001$, see Figure 3).

In the toddlers with diaries (80 intervals) the child was recorded as having eaten in the previous 2 hours in 53 (66%) intervals, drunk in 63 (79%), passed urine in 71 (89%) and passed stool in 27 (34%). Recent eating and passage of stool were both associated with increased weight gain (Table 2). Drinking was also significantly positively associated with weight gain in univariable analysis, but not after adjustment for time, and it became negative when mutually adjusted. There was no association with passing urine. These associations did not explain the difference in weight gain during the day compared to overnight, which increased when adjusted for all the intake and output variables. Adjusting for age and weight made no material difference to the results (data not shown).

DISCUSSION

Remarkably little is known about how weight varies over time in young children. One previous study examined this question, weighing seven infants over two days (4), but ours is the first study to look at weight variability in toddlers. In a previous paper we described how the estimate for noise in infants was much less than the average expected weight gain over 4 weeks (2), but in the present sample of older children noise was much greater and weight gain much smaller; beyond the age of 12 months noise was greater than the average expected weight gain over 4 weeks, and nearing the average expected weight gain over 8 weeks. A recent study in a less affluent setting collected daily weights in a group of Gambian infants (5). The study used a spline curve to "smooth out minor day-to-day fluctuations" so that the degree of day-to-day variability in their population is not described, but an illustrative figure suggests that some day-to-day fluctuations on a similar scale (100-200g) to those found in our younger group.

Noise, i.e. the standard deviation of short-term weight change, corresponds to what is often called measurement error. However, in this case we can compare the measurement error of a single weight, i.e. the technical error of measurement (TEM) based on two weights collected at the same time (4-20g), to variability in weight change seen over hours and days which was considerably larger, being 117g in infants and 313g in toddlers. This illustrates how much weight varies in the short term. For weight gain measured over say 4 or 8 weeks the observed gain is the true gain plus the short-term variability (noise), which may be positive or negative. The concern here is the possibility of apparent but spurious weight loss in a child, whose true rate of weight gain is average. This happens if the noise is sufficiently large and negative to cancel out the true gain, making the observed weight gain zero or negative. The chance of this happening can be calculated by dividing minus the expected gain by the noise, a form of z-score that can be converted to a probability. In toddlers the expected gain over 4 weeks is around 200g and the noise is 313g, and here the chance of spurious weight loss is about 1 in 4. Over 8 weeks, with twice the growth increment, the chance falls to 1 in 10. However, for most of infancy the chance of seeing spurious weight loss is <1%, as noise is far smaller, and weight gain much greater.

The lower level of noise seen in infants is likely to reflect their milk-based diet, consumed in frequent small amounts both day and night. Unlike the infants, the toddlers' weight increased by day and decreased overnight. Eating within the previous 2 hours was associated with increased weight, but drinking or passing urine was not. The extent to which ingested milk can be reliably detected by weighing has been debated in relation to breast feeding. One study in newborn infants found that weighing was accurate on average, with little or no bias, but with wide variability (6). However, by the age of 12 months children rely much less on milk, which may be why drinking was not associated with weight gain.

It is commonly thought that recently passing a large motion leads to weight loss, but these results suggest the opposite. The effect of passage of stool was substantially reduced by adjusting for eating and time of day, while the effect of eating was increased by adjusting for passage of stool, so having passed stool may well be a marker for having eaten a substantial meal, with triggering of the gastrocolic reflex. However, it is also possible that passage of stool itself encourages increased intake. A large study of children with constipation showed that successful treatment, i.e. clearing the accumulated stool, was associated with weight gain rather than loss (7). Passing urine had no effect, possibly because this occurred steadily throughout day and night.

A strength of this study was that inter-observer variability in weight was also assessed with blinding of each observer to the true weight. This revealed very little variability for children weighed twice at the same time, although repeat weights were more variable on the first occasion than the second. This suggests that parents' accuracy improved as they became more familiar with the procedure. This study is relatively small, but the number of intervals per child adds precision, and for the intake and output analysis, the multiple intervals per child add the strength that children were acting partly as their own controls. In particular this sample lacked children aged 10-12 months, so the pattern of change from the first to the second year is not clear. However, a future larger study could replicate these findings and also provide more detail about how variability varies with age.

A further limitation is that the snowball sampling means that the sample may not be fully representative of the general population. Parents were asked to record intake and output only in the 2 hours prior to each weight, which is informative about likely short-term changes, but means that we lack a complete picture of intake and output.

In conclusion, while incidental variability in weight in infants will usually be much smaller than their expected gain, in toddlers it is important to recognise that the true weight trajectory may be 300g higher, or lower, than the weight recorded at any one time. The longer the time interval between weights, the more likely it is that the observed weight increment will give an accurate picture, so in toddlers there should ideally be an interval of at least 8 weeks between weights. When accurately assessing change over a shorter time interval is important, for example when a child's weight appears to be faltering, clinicians can reduce measurement error by weighing at roughly the same time each day and not within 2 hours of a meal.

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Data sharing: The data reported in the manuscript can be found at ????.

Contributorship

CW planned the study and with TC undertook the analysis and wrote the paper. HS and FH-planned and conducted data collection and undertook initial analyses. CW will act as the guarantor

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Table 1. Weight and weight variability by age

Age category (months)	Number	Mean (SD) Weight Z	P ANOVA	Number (%) girls	Chi [2]	Noise* (g)
6m or less	8	-0.080 (1.01)		6 (75%)		104
6-12	12	0.268 (1.2)		6 (50%)		124
12-24	13	-0.286 (0.89)		4 (31%)		334
24-36	8	0.439 (0.44)	0.23	4 (50%)	0.26	273
0-12	20	-0.192 (1.14)	P t-test	12 (60.0%)		117
12-36	21	0.149 (0.773)	0.26	8 (38.1%)	0.22	313
Total	41	-0.017 (0.971)		20 (48.8%)		238

*SD of difference between weights

Table 2. Analysis per pair of successive measurements of associations of diarised events and time of day with weight change (kg) in toddlers (80 intervals with linked diary entries from 20 children).

Values are regression coefficients (B [SE]) with weight change as outcome.

Within previous 2 hours	Univariate association B (SE)	p	Adjusted for Time[1] B (SE)	p	Fully Adjusted[2] B (SE)	p
Ate	0.34 (0.07)	<0.001	0.18 (0.07)	0.007	0.24 (0.09)	0.006
Drank	0.29 (0.09)	0.001	0.06 (0.08)	0.4	-0.15 (0.10)	0.1
Passed urine	0.04 (0.12)	0.7	-0.10 (0.09)	0.3	-0.08 (0.09)	0.3
Passed stool	0.24 (0.07)	0.002	0.14 (0.06)	0.03	0.12 (0.06)	0.05
Time[1]	0.42 (0.06)	<0.001			0.35 (0.06)	<0.001

[1]Whether pairs of weights collected across day or night

[2]Linear regression model including Time, Ate, Drank, Passed urine and Stool variables

Figure 1: Scatterplot of change between successive weights plotted against age.

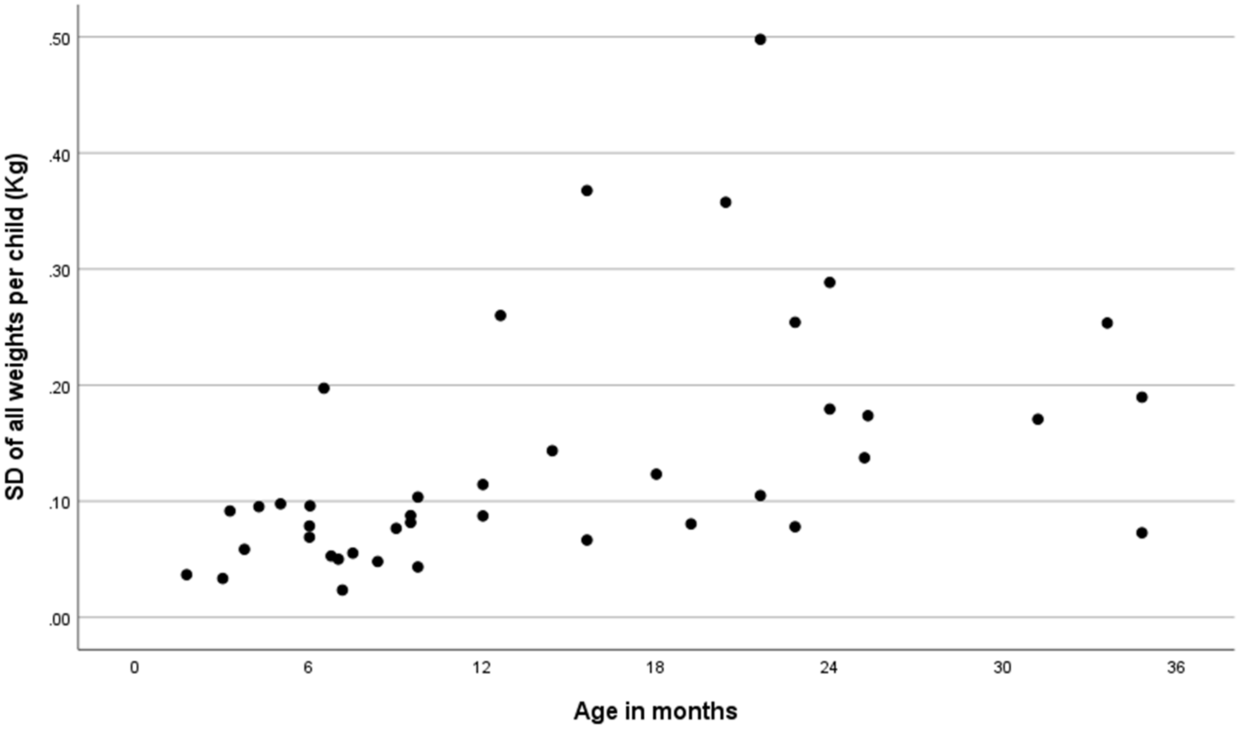

Figure 2 How estimated noise at different ages and intervals related to expected weight gain (based on WHO-UK standard mean of boys' and girls' 50th centile)

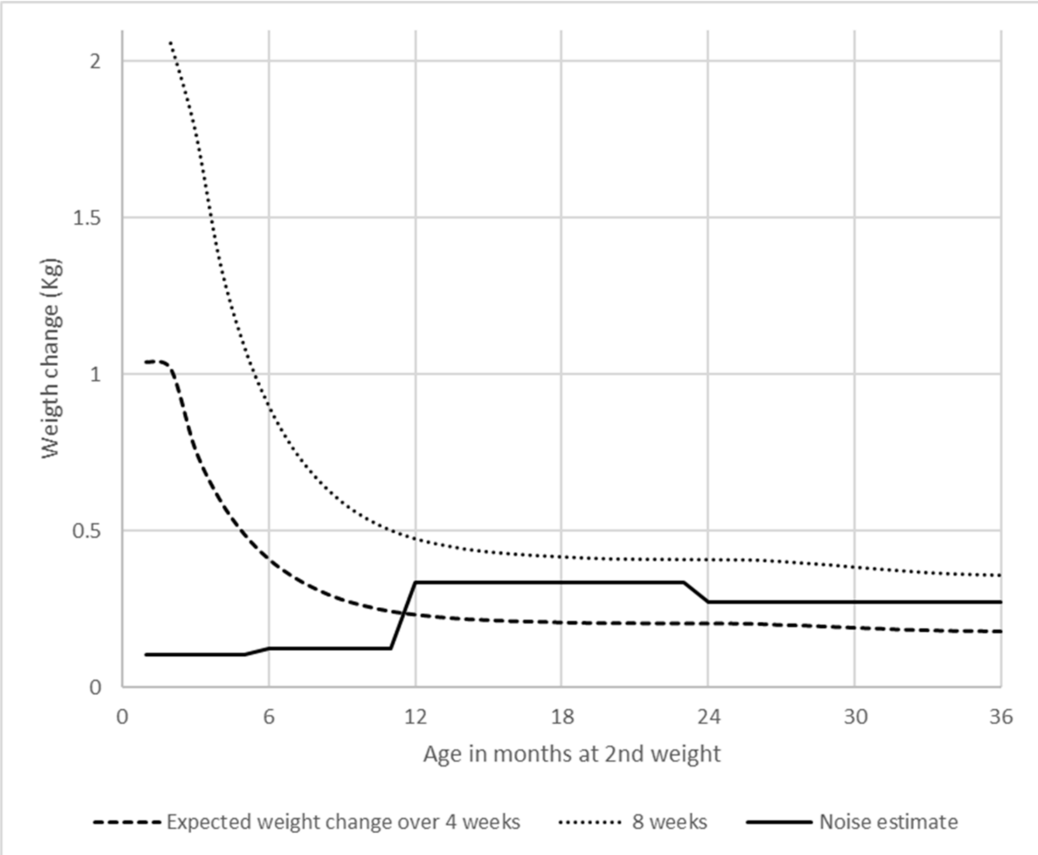

Figure 3: Scatterplot of change between successive weights plotted against age, with regression lines fitted for pairs of weights measured overnight and those across day.