Weight velocity in addition to latest weight does not improve the identification of wasting, or the prediction of stunting and mortality: a longitudinal analysis using data from Malawi, South Africa, and Pakistan

Charlotte M. Wright, Fanny Petermann-Rocha, Ruth Bland, Per Ashorn, Shakila Zaman, Frederick K. Ho

PII: S0022-3166(24)00350-X

DOI: https://doi.org/10.1016/j.tjnut.2024.06.011

Reference: TJNUT 654

To appear in: *The Journal of Nutrition*

Received Date: 21 March 2024

Revised Date: 28 May 2024

Accepted Date: 21 June 2024

Please cite this article as: C.M Wright, F. Petermann-Rocha, R. Bland, P. Ashorn, S. Zaman, F.K Ho, Weight velocity in addition to latest weight does not improve the identification of wasting, or the prediction of stunting and mortality: a longitudinal analysis using data from Malawi, South Africa, and Pakistan, *The Journal of Nutrition*, https://doi.org/10.1016/j.tjnut.2024.06.011.

Weight velocity in addition to latest weight does not improve the identification of wasting, or the prediction of stunting and mortality: a longitudinal analysis using data from Malawi, South Africa, and Pakistan.

Charlotte M Wright[1], Fanny Petermann-Rocha[2], Ruth Bland[3], Per Ashorn[4], Shakila Zaman[5], Frederick K Ho[6]

1. School of Medicine, Dentistry & Nurising, University of Glasgow, Glasgow, UK
2. Centro de Investigación Biomédica, Facultad de Medicina, Universidad Diego Portales, Santiago, Chile
3. School of Medicine, University of Glasgow, UK
4. Center for Child Health Research, Tampere University and Tampere University Hospital, Tampere, Finland
5. Department of Public Health, University of Health Sciences, Lahore, Pakistan
6. School of Health and Wellbeing, University of Glasgow

Corresponding author

Prof Charlotte M Wright; charlotte.wright@glasgow.ac.uk

Sources of support: This analysis received no specific funding. The individual cohorts were funded from a wide ranges of sources: Lungwena Child Survival Study (LCSS): Academy of Finland, Emil Aaltonen Foundation, Foundation for Paediatric Research, Medical Research Fund of Tampere University Hospital, the Research Foundation of Mannerheim League for Child Welfare, and the Research Foundation of the University of Tampere. Africa Centre Vertical Transmission Study: Wellcome Trust UK 063009/Z/00/2. Lahore longitudinal study: SAREC (Swedish Agency for Research Cooperation with Developing Countries) and King Edward Medical College, Lahore, Pakistan

Abbreviations: AW (attained weight), AUC: area under curve, LAZ (length for age z-score), LMIC (low and middle income countries), MAM (moderate acute maltnurition), SAM (severe acute malnutrition), WAZ (weight for age z-score), WFH (weight-for-height), WV (weight velocity), WVZ2 (weight velocity z-score over 2 months) WVZ6 (weight velocity z-score over 6 months).

Abstract

Background: In low/middle-income countries, most nutritional assessments use the latest weights, without reference to growth trajectory.

Objective: This study explores whether velocity, in addition to the latest weight, improves the prediction of wasting, stunting or mortality in the first two years of life.

Methods: We analysed a combined data set with weight and height data collected monthly in the first year of 3447 children from Pakistan, Malawi, South Africa, with height and survival recorded till 24 months. The main exposures were weight-for-age z-score (WAZ) at the end of each 2-month period and weight velocity-for-age z-score (WVZ_2) across that period. The outcomes were wasting, stunting or all-cause mortality in the next 1-2 months. As a sensitivity analysis, we also used WVZ over 6 months (WVZ_6), with matching WAZ. Cox proportional hazard models with repeated growth measures were used to study the association between exposures and mortality. Mixed Poisson models were used for stunting and wasting.

Results: Children who were already stunted or wasted were most likely to remain so. WVZ_2 was associated with a lower risk of subsequent stunting (RR 0.95; 95% CI 0.93-0.96), but added minimal prediction (difference in AUC = 0.004) compared to a model including only WAZ. Similarly, WVZ_2 was associated with wasting (RR 0.74; 95% CI 0.72-0.76) but the prediction was only marginally greater than for WAZ (difference in AUC = 0.015). Compared to WAZ, WVZ_6 was less predictive for both wasting and stunting. Low WVZ_6 (but not WVZ_2) was associated with increased mortality (HR 0.75, 95% CI 0.67-0.85), but added marginal only prediction to a model including WAZ alone (difference in C = 0.015).

Conclusions: The key anthropometric determinant of impending wasting, stunting, and mortality appears to be how far below the normal range the child's weight is, rather than how they reached that position.

Keywords: Children; Mortality; Growth Disorders; Stunting; Weight.

Introduction

Child undernutrition remains a major global health concern (1). World Health Organisation (WHO) definitions of malnutrition rely on single measures of weight and length/height and, more recently, mid upper arm circumference, as well as the combination of weight and length/height to give weight for height (WFH). The most common measure is that of weight, usually adjusted for age via a lookup table, plotting on a chart or converting to a standard deviation (Z) score. A weight for age Z score (WAZ) <-2 is defined as moderate malnutrition and <-3 as severe, while a length for age Z score (LAZ) <-2 is defined as stunting (2). Regularly weighing aims to identify children who have lost or gained weight more slowly than their peers and are malnourished, so a measure that determines children with low weight velocity (WV) might be expected to be more discriminating than attained weight (AW) alone. In high-income countries, this has led to the concept of failure to thrive (FTT) or weight faltering, where the diagnosis depends on low WV based on two or more weights, at least while a child is within the normal range (3).

In contrast, in low- and middle-income countries (LMIC), decisions tend to be based only on the current weight, as interpretation of serial measurements requires more detailed record-keeping and WHO definitions of malnutrition include no velocity elements (4). However, the WHO growth chart project has published age and sex-standardised norms for weight velocity over 4- and 8-week intervals (5) and they have argued that velocity measures are helpful in predicting later stunting (6). As severe malnutrition (SAM) becomes less common (7), the accurate diagnosis of moderate malnutrition (MAM) becomes more important, to target treatment to children who are most likely to benefit. Using only a low AW will also identify children who were born small but have grown steadily since birth and supplementary feeding could even harm these children (8). Thus, a secondary screening measure of velocity could potentially be used to improve the specificity of diagnoses.

Few studies have examined whether velocity improves the prediction of adverse growth outcomes, compared to using a single weight (7, 8). Only one has considered outcomes beyond the age of 6 months or used increments greater than one month (9). Thus, it is unclear whether velocity adds value in addition to the latest weight alone, and if so, when, and over what time interval weight velocity might usefully be measured.

We thus aimed to use a large combined historical data set of longitudinal growth data, with a high prevalence of malnutrition, to examine the value of WV, in addition to AW, in identifying the onset of wasting and predicting stunting or mortality at different ages, and over differing time intervals.

Methods

This prospective study used data from three cohort studies conducted in low or middle income countries, all with monthly measurements collected for at least the first 12 months and outcome of interest up to 24 months. These were the Lungwena Child Survival Study (Malawi), the Africa Centre Vertical Transmission Study (South Africa), and the Lahore longitudinal study (Pakistan). Each study is briefly described below.

Included cohort studies

The Lungwena Child Survival Study was a cohort study of 795 women recruited between 1995 and 1996 and their newborn children prospectively studied (10, 11). Children were measured monthly to 18 months, then every three months up to 36 months. Children were measured at home by a research assistant using portable spring scales and length boards (12).

The Africa Centre Vertical Transmission Study study registered 2938 children (half HIV-positive) from seven rural, one semi-urban, and one urban primary health care clinic in KwaZulu-Natal, in a nonrandomised intervention cohort study between 2001 and 2005 (13, 14). Weight and lengths were collected by research staff, using the WHO-recommended protocol, monthly until 12 months, then every three months to 24 months (12).

The Lahore longitudinal study enrolled infants born between 1984 and 1994, with 1314 from a village area, 572 from a peri-urban slum, 921 from an urban slum, and 339 from a middle-class neighbourhood, and followed them monthly from birth up to 36 months (15, 16). All infants were weighed and measured at home by specially trained research assistants, with the measuring technique checked monthly and instruments checked weekly (12, 17).

In the three studies, all deaths were recorded, but their causes were not recorded consistently between datasets. Sociodemographic information (age, sex, and country of origin) was self-reported. Moreover, HIV-positive mothers and subsequent HIV-positive children were excluded from the analyses.

Statistical analyses

The three datasets were combined into one database (excluding all HIV-positive mothers) and measurements were expressed as Z scores compared to the WHO growth standard (18).

Stunting was defined as length for age (LAZ) <-2SD and wasting as weight for length (WLZ) <-2. The analysis was then conducted per measurement rather than per child. For each attained weight, the exposures of interest was the Z score for that weight (WAZ) and the velocity for age (WVZ) across the period up to that attained weight, calculated using the WHO velocity standards(5) for both 2 and 6 month intervals. The outcome was whether or not the child was stunted or wasted at the next monthly measurement, or whether they had died. Attained WLZ and LAZ were treated as secondary or additional exposures.

Prediction models were constructed using weight velocity and the attained growth parameters at the end of the weight velocity period, to predict the next observation of wasting, stunting, or mortality. Since each growth measurement was used to predict the subsequent period’s wasting and stunting risk, mixed Poisson models with repeated growth measures were used to study the associations. All observations were included in the model to maximise power while intra-personal correlations were captured as a random intercept. Results are reported as risk ratios (RR) with their respective 95% CI. Model predictive performance was assessed with the area under the receiver operating characteristic curve (AUC). The main analyses were adjusted for age at assessment, sex, and country of origin. In addition, analyses were stratified for incident and recurrent wasting/wasting for the predictors that had the highest AUC.

Cox proportional hazard models with repeated growth measures were used to study the association between exposures and mortality rate. The outcome variable was time to event (either death or censoring). The basic analyses were adjusted for age at assessment, sex, and country of origin (model 1). Additional models included the mutual adjustment among the growth parameters. Analyses are reported as hazard ratios (HR) with 95% confidence intervals (CI). In the mortality analysis, the predictive ability was quantified using Harrell's C-index – which estimates the probability of concordance between observed and predicted responses (19).

Finally, sensitivity analyses were used to investigate whether the associations observed differed by age (≤ and > 6 months). The interaction between binary age group (≤ vs. > 6 months) and weight variables were included in the corresponding regression models and can be interpreted as the ratio of RR (for wasting and stunting) and ratio of HR (for mortality). A ratio > 1 indicates that the association of the weight variable with the outcome is stronger in the older (> 6 months) group.

R 4.0.5 software was used to perform all analyses. A p-value ≤ 0.05 was considered statistically significant.

Results

The baseline characteristics of the included data are shown in Table 1. Of the 3447 children with any pairs of growth data, 98 children died, and in a third of these this followed a weight <-2SD. Of the included weights, the majority (78%) were within normal range, but 20% were <-2 (underweight) and only 1% were >2. Using the first measurements available near to birth, 11.8% of children were < -2 WAZ and 14.4% < -2 LAZ. The majority of underweight measures came from the Pakistan peri-urban & village cohorts. On average children were already below expected length by age 1 month and dropped to an average 2SD below the mean by the second year of life, 14% were already < -2 LAZ (Figure 1). Their weight showed a similar but less extreme pattern. Weight for length rose in the first few weeks and remained close to expected levels for the first 6 months, then dropped slightly below thereafter.

The associations of WAZ and WVZ with subsequent wasting and stunting were shown in Table 2. For both wasting and stunting, after adjustment for age, sex, country of origin and already being wasted or stunted, respectively, WVZ2 was a stronger predictor than WVZ6, but both were lower than for WAZ alone. The model including WVZ2 as well as WAZ had marginally higher prediction performance for subsequent wasting (AUC gain 1.5%) than the model with only WAZ, but for predicting stunting: the model including WAZ and WVZ2 the AUC was almost unchanged (AUC gain 0.4%).

The associations for those who were not wasted or stunted at the time of the attained WAZ (incident cases) and for children who were already stunted or wasted are shown in Table 3. This revealed that, although both WAZ and WVZ2 were more predictive of incident cases than persistence in prevalent cases, WVZ essentially added no extra prediction of incident cases. It did, however, increase the prediction of recovery from wasting (change in AUC 9.8%) but only marginally from stunting (change in AUC 1.4%).

Associations of growth parameters with mortality are shown in Table 4. Adjusted just for age, sex, and country of origin (Model 1), WAZ, WLZ, and WVZ (6-month interval) were separately associated with lower mortality risk, while WVZ (2-month interval) and LAZ were not significantly associated with mortality. Among combinations of the 3 significant predictors, the combination of WAZ and WVZ (6-month interval) yielded the strongest prediction (C-index 0.8842), slightly greater than using WAZ (C-index 0.8647) or WVZ-6 alone (0.8718) but the overall gain was still only 2%.

Supplementary Tables 1-3 show the analysis of potential interaction with age group. On predicting wasting, in the combined model, WAZ showed a 12% increased association (Ratio of RR = 0.88; 95% CI 0.81-0.95) in older children, while WVZ-2 was 6% greater (Ratio of RR = 1.06; 95% CI 1.01-1.12). There was no evidence for age interactions for predicting stunting and mortality.

Discussion

This study used data from three cohort studies to describe the extent to which recent changes in weight (velocity) added to the accuracy of prediction of later wasting, stunting and mortality, compared to a single weight alone. Surprisingly, combining weight velocity with attained weight added little or no additional predictive value, except in predicting whether already wasted children would recover.

This finding is in keeping with the limited number of other papers that have directly compared velocity with single measures, mostly in relation to mortality. Two early studies found that attained weight and height for age performed better than weight or height velocity as discriminators of mortality (20, 21), while a more recent paper found little difference between various single measures and velocity (22). One group has found velocity to be a stronger predictor of mortality in one data set (23), but in a second set they found no increased prediction when adding velocity (24). In another study, the same group also considered predicting wasting and stunting and found that velocity increased prediction up to age 2 months (24), but not at later ages (9).

There are many possible reasons why velocity may not be a useful discriminator. Velocity is vulnerable to error as it requires two measurements, both with a degree of measurement error (e.g. instrument imprecision and differences in procedures) plus the variability of weight over short intervals due to ingestion and elimination (25). Although these data were collected as part of research studies, they were largely collected in real life situations where one could speculate that at one visit a young child might have just eaten and drunk largely, while at the next they might have fasted or just emptied their bowels or bladder. These combined are thus inevitably less accurate than a single weight measurement. Thus, a child could show a large meaningless variation (‘noise’), from one time to the next that has no long-term significance, but has the potential to drown out true meaningful variation - the‘signal’ (25).

It must also be born in mind that weight velocity is calculated between two measurements, and in utero growth could not be measured. If the decline in growth occurred in utero, the size at birth may be low, but there will be no observable decline in velocity. As a group, these children had a high prevalence of stunting, illustrated by the fact that the mean LAZ in the 2nd year was close to -2 (i.e. 2 SD below mean). It has been well shown that a high proportion of stunting has already occurred very early in the first year (26). Other studies have shown that in uncompromised environments most children with slow intrauterine growth will show rapid catchup in the first 4 months (27), but in suboptimal circumstances recovery from stunting is rare (26). Thus most of these children remain at a similar centile, rather than a showing a detectable decline. This may also apply to the onset of wasting; a previous study in young infants that compared attained weight to velocity and skinfolds as a measure of low fat stores, found that a low weight was highly specific for both low velocity and low fat, but that only 40% of those with low fat had shown slow weight gain (28), suggesting that they had started life with low fat stores and failed to acquire fat, rather than faltering.

Finally, it should be recognised that velocity may vary rapidly over time, resulting in varying measurements dependent on when the measurement was taken and the duration where velocity is calculated. A recent study collected daily weights in a group of Gambian infants used a spline curve to “smooth out minor day-to-day fluctuations” and found that short episodes of weight loss were common (mean 18 days), but these were followed by a similar period (mean 17 days) of catchup (29). Depending on the times when weights were collected, the same child might thus be labelled as having very low or very high velocity (Figure 2). Over a longer period, the net effect may have been slower than expected weight gain, but it had two sources of errors (25). This deviation can equally be detected in most children simply using weight for age, as this describes how much the weight deviates from the average for that age, with only one error. So weight for age will always tend to be more accurate than the net velocity in initially average children, who will always be in a majority.

Strengths and limitations

This study was able to combine data from three cohorts with comparable measurements, which enabled us to answer the research question with more events than analysing each cohort separately. Nonetheless, this study is not without limitations. Firstly, as a group, these children had very high rates of stunting, but our earlier description of this cohort showed that while incident wasting was higher than expected, it was much less common. (12). So in this setting, variations in WAZ may be more likely to reflect slowing of growth rather than short-term weight loss. Data collection was carried out more than 20 years ago when mortality and severe acute malnutrition were generally more common in the area. Thus, these findings may not be representative of modern populations. We have not considered the potentially modifying role of diet, in particular duration of breast feeding and age of first solids, environmental conditions or socioeconomic conditions, as these were not consistently collected between data sets. Similarly, we have not considered the role of birth length and weight in the analysis, as this study focus on the prediction value of weight velocity in practice, where birth length and weight is often not available.

Implications

The usual practice, which concentrates on the current weight, turns out to be the better than the proposed alternatives, as well as the easiest means of detecting wasting or predicting future adverse events. It is arguably reassuring that this analysis found no justification for incorporating weight velocity measures in routine screening programmes, which already struggle to find time to process even single weights and heights. Incorporating the change from an earlier weight adds considerable complexity in practice. This would require the earlier weight to be accessed and the change interpreted, although recent developments in digital support for growth monitoring have the potential to make the interpretation easier (30).

The one possible exception for this is in the assessment of children with MAM or SAM (as indicated by wasting in this study), where the recent growth pattern substantially improved the prediction of persistence or recovery. This may lend support to the practice in many nutrition clinics of monitoring weight gain over time, not just attained weight, although this is not recommended by WHO (4).

In conclusion, although theoretically useful in detecting and predicting low growth and mortality, velocity measures add little or no predictive power, probably due to their increased imprecision compared to a single recent weight and the challenge of measuring them over the relevant time interval. The key anthropometric determinant of impending wasting, stunting, and mortality appears to be how far below the normal range the child's weight is, rather than how they reached that position.

Acknowledgements

CMW, FPR, FKH designed the study and jointly-wrote the first draft. FPR and FKH analysed the data. RB, PA, SZ interpreted the data and critically revised the manuscript. CMW, FPR, RB, PA, SZ, and FKH have read and approved the final version of the manuscript .

References

1. Victora CG, Christian P, Vidaletti LP, Gatica-Domínguez G, Menon P, Black RE. Revisiting maternal and child undernutrition in low-income and middle-income countries: variable progress towards an unfinished agenda. The Lancet. 2021;397(10282):1388-99.
2. UNICEF. Levels and trends in child malnutrition: UNICEF / WHO / World Bank Group Joint Child Malnutrition Estimates: Key findings of the 2023 edition. 2023.
3. NICE. Faltering growth: recognition and management of faltering growth in children. London: National Institute for health and care excellence 2017.
4. WHO. WHO guideline on the prevention and management of wasting and nutritional oedema (acute malnutrition) in infants and children under 5 years. Geneva: World Health Organization; 2023.
5. WHO. WHO Child Growth Standards: Growth velocity based on weight, length and head circumference: Methods and development. Geneva; 2009 2009.
6. Onyango AW, Borghi E, de Onis M, Frongillo EA, Victora CG, Dewey KG, et al. Successive 1-month weight increments in infancy can be used to screen for faltering linear growth. The Journal of Nutrition. 2015;145(12):2725-31.

7. UNICEF, WHO. Levels and trends in child malnutrition: key findings of the 2019 Edition of the Joint Child Malnutrition Estimates. Geneva: World Health Organization; 2020.

8. WHO. Guideline: assessing and managing children at primary health-care facilities to prevent overweight and obesity in the context of the double burden of malnutrition. . Geneva: World Health organization 2017.

9. Schwinger C, Fadnes LT, Shrestha SK, Shrestha PS, Chandyo RK, Shrestha B, et al. Predicting Undernutrition at Age 2 Years with Early Attained Weight and Length Compared with Weight and Length Velocity. Journal of Pediatrics. 2017;182:127-32 e1.

10. Espo M, Kulmala T, Maleta K, Cullinan T, Salin ML, Ashorn P. Determinants of linear growth and predictors of severe stunting during infancy in rural Malawi. Acta Paediatrica. 2002;91(12):1364-70.

11. Maleta K, Virtanen S, Espo M, Kulmala T, Ashorn P. Timing of growth faltering in rural Malawi. Archives of Disease in Childhood. 2003;88(7):574-8.

12. Wright CM, Macpherson J, Bland R, Ashorn P, Zaman S, Ho FK. Wasting and Stunting in Infants and Young Children as Risk Factors for Subsequent Stunting or Mortality: Longitudinal Analysis of Data from Malawi, South Africa, and Pakistan. The Journal of Nutrition. 2021;151(7):2022-8.

13. Patel D, Bland R, Coovadia H, Rollins N, Coutsoudis A, Newell M-L. Breastfeeding, HIV status and weights in South African children: a comparison of HIV-exposed and unexposed children. Aids. 2010;24(3):437-45.

14. Bland R, Coovadia H, Coutsoudis A, Rollins N, Newell M. Cohort profile: mamanengane or the Africa centre vertical transmission study. International Journal of Epidemiology. 2010;39(2):351-60.

15. Karlberg J, Ashraf R, Saleemi M, Yaqoob M, Jalil F. Early child health in Lahore, Pakistan: XI. Growth. Acta Paediatrica. 1993;82:119-49.

16. Zaman S, Jalil F, Saleemi MA, Ashraf RN, Mellander L, Hanson LÅ. Changes in feeding patterns affect growth in children 0–24 months of age living in socioeconomically different areas of Lahore, Pakistan. Integrating Population Outcomes, Biological Mechanisms and Research Methods in the Study of Human Milk and Lactation. 2002:49-56.

17. Jalil F, Lindblad B, Hanson L, Khan S, Ashraf R, Carlsson B, et al. Early child health in Lahore, Pakistan: I. Study Design. Acta Paediatrica. 1993;82(s391):3-16.

18. Group WMGRS, de Onis M. WHO Child Growth Standards based on length/height, weight and age. Acta Paediatrica. 2006;95:76-85.

19. Harrell FE, Jr., Lee KL, Mark DB. Multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. Statistics in Medicine. 1996;15(4):361-87.

20. Briend A, Garenne M, Maire B, Fontaine O, Dieng K. Nutritional status, age and survival: the muscle mass hypothesis. European Journal of Clinical Nutrition. 1989;43(10):715-26.

21. Bairagi R, Chowdhury MK, Kim YJ, Curlin GT. Alternative anthropometric indicators of mortality. The American Journal of Clinical Nutrition. 1985;42(2):296-306.

22. MO'Neill S, Fitzgerald A, Briend A, Van den Broeck J. Child mortality as predicted by nutritional status and recent weight velocity in children under two in rural Africa. The Journal of Nutrition. 2012;142(3):520-5.

23. Schwinger C, Fadnes LT, Van den Broeck J. Using growth velocity to predict child mortality. The American Journal of Clinical Nutrition. 2016;103(3):801-7.

24. Wang D, Schwinger C, Urassa W, Berhane Y, Strand TA, Fawzi WW. Comparing Attained Weight and Weight Velocity during the First 6 Months in Predicting Child Undernutrition and Mortality. The Journal of Nutrition. 2022;152(1):319-30.

25. Wright CM, Haig C, Harjunmaa U, Sivakanthan H, Cole TJ. Assessing the optimal time interval between growth measurements using a combined data set of weights and heights from 5948 infants. Archives of Disease in Childhood. 2022;107(4):341-5.

26. Benjamin-Chung J, Mertens A, Colford Jr JM, Hubbard AE, van der Laan MJ, Coyle J, et al. Early-childhood linear growth faltering in low-and middle-income countries. Nature. 2023;621(7979):550-7.

27. Shi H, Yang X, Wu D, Wang X, Li T, Liu H, et al. Insights into infancy weight gain patterns for term small-for-gestational-age babies. Nutrition Journal. 2018;17:1-9.

28. Ezeofor IO, Garcia AL, Wright CM. Criteria for undernutrition screening in hospitalised infants under 6 months: a diagnostic accuracy study in a resource-poor setting. Archives of Disease in Childhood. 2020;105(6):524-9.

29. Naumenko DJ, Dykes J, O'Connor GK, Stanley Z, Affara N, Doel AM, et al. A Novel method for the identification and quantification of weight faltering. American Journal of Physical Anthropology. 2021;175(1):282-91.

30. Wright CM, Chapman S, Cole TJ. How can we best chart children’s growth in the paperless age? The UK experience. Archives of Disease in Childhood. 2024;109(2):78-82.

Table 1. Baseline characteristics per attained weight WAZ categories

	Baseline WAZ categories		
	<-2	-2 to 2	>2
Total number of measurements, n (%)	4,167 (20.4)	15,953 (78.3)	265 (1.3)
Number (%) in each WAZ category by cohort:			
Malawi	842 (20.2)	2,734 (17.1)	4 (1.5)
South African and Pakistan middle class	154 (3.7)	3,968 (24.9)	201 (75.9)
Pakistan peri-urban & village	2,303 (55.3)	4,595 (28.8)	0
Pakistan urban slum	868 (20.8)	4,656 (29.2)	60 (22.6)

n: number; WAZ: weight-for-age z-score

Table 2. Associations of attained weight and weight velocity in one period, with wasting and stunting in the next period.

Predicting wasting in next period	RR (95% CI)	AUC	Change in AUC	
Model 1		0.872 (0.861-0.884)	REF	
Wasting in this period	9.91 (8.3; 12.8)			
Model 2		0.916 (0.908-0.924)	4.5%	REF
Wasting in this period	3.84 (3.1; 4.7)			
WAZ	0.66 (0.6; 0.7)			
Model 3		0.888 (0.878-0.899)	1.7%	
Wasting in this period	11.8 (10.5; 13.2)			
WVZ_2	0.76 (0.74; 0.79)			
Model 4		0.869 (0.858-0.880)	-0.3%	
Wasting in this period	11.8 (10.5; 13.2)			
WVZ_6	0.83 (0.81; 0.86)			
Model 5		0.931 (0.927-0.941)	6.0%	1.5%
Wasting in this period	4.06 (3.4; 4.9)			
WAZ	0.62 (0.58; 0.66)			
WVZ_2	0.74 (0.72; 0.76)			
Predicting stunting in next period				
Model 1		0.910 (0.905-0.915)	REF	
Stunting in this period	6.61 (6.2; 7.0)			
Model 2		0.929 (0.925-0.934)	2.0%	REF
Stunting in this period	5.30 (4.9; 5.7)			
WAZ	0.86 (0.85; 0.88)			
Model 3		0.913 (0.909-0.918)	0.3%	
Stunting in this period	6.62 (6.2; 7.1)			
WVZ_2	0.96 (0.95; 0.97)			
Model 4		0.912 (0.907-0.917)	0.2%	
Stunting in this period	6.63 (6.2; 7.1)			
WVZ_6	0.96 (0.95; 0.98)			
Model 5		0.933 (0.929-0.937)	2.3%	0.4%
Stunting in this period	5.22 (4.99; 5.6)			
WAZ	0.85 (0.84; 0.87)			
WVZ_2	0.95 (0.93; 0.96)			

Data presented as risk ratios (RR) and their 95% CI using linear mixed-effect models. All models were adjusted for age, sex and country of origin and and then mutually adjusted for all variables listed. WAZ: weight-for-age z-score; WVZ_2: Weight velocity z-score 2-month interval. WVZ_6: Weight velocity z-score 6-month interval. All Relative risks were P<0.001

Table 3. Associations of attained weight and weight velocity with subsequent wasting and stunting in incident and prevelant existing cases

	Risk of incident wasting in non-wasted childen			Risk of continued wasting in already wasted childen		
	RR (95% CI)	p-value	AUC	RR (95% CI)	p-value	AUC
Predicting wasting						
Model with WAZ only	0.49 (0.45-0.53)	<0.001	0.912 (0.902-0.922)	0.84 (0.80-0.88)	<0.001	0.707 (0.683-0.733)
Model WVZ2 only	0.70 (0.70-0.70)	<0.001	0.916 (0.604-0.928)	0.83 (0.79-0.86)	<0.001	0.743 (0.718-0.769)
Model with both			0.914 (0.902-0.925)			0.805 (0.783-0.828)
WAZ	0.46 (0.42-0.50)	<0.001		0.83 (0.79-0.87)	<0.001	
WVZ2	0.67 (0.64-0.70)	<0.001		0.82 (0.79-0.86)	<0.001	
Gain in AUC by adding WVZ to model			0.2%			9.8%
	Risk of incident stunting in non stunted childen			Risk of continued stunting in already stunted childen		
Model with WAZ only	0.52 (0.49-0.55)	<0.001	0.837 (0.826-0.848)	0.94 (0.92-0.96)	<0.001	0.761 (0.742-0.780)
Model WVZ2 only	0.89 (0.86-0.91)	<0.001	0.832 (0.820-0.844)	0.99 (0.97-1.00)	<0.001	0.678 (0.656-0.701)
Model with both			0.831 (0.825-0.847)			0.775 (0.757-0.793)
WAZ	0.49 (0.46-0.52)	<0.001		0.93 (0.91-0.96)	<0.001	
WVZ2	0.84 (0.81-0.52)	<0.001		0.98 (0.97-1.00)	0.02	
Gain in AUC by adding WVZ to model			-0.1%			1.4%

Data presented as risk ratios (RR) and their 95% CI using linear mixed-effect models. The created groups were: people who had wasting/stunting at baseline (yes/no) vs those who developed later (yes/no). The main analyses were adjusted for age, sex, country of origin and wasting/stunting status in the last period. WAZ: weight-for-age z-score; WVZ: Weight velocity z-score.

Table 4. Associations of attained height, weight and weight velocity with mortality

	HR (95% CI)	p-value	C-index (95% CI)	Change in C-index
Each variable added singly				
WAZ = Model 1	0.84 (0.73-0.98)	0.023	0.8647 (0.8263-0.9032)	REF
WLZ	0.83 (0.72-0.97)	0.02	0.8626 (0.8234-0.9018)	-0.2%
LAZ	0.91 (0.77-1.08)	0.30	0.8592 (0.8203-0.8980)	-0.6%
WVZ (2-month interval)	0.93 (0.80-1.06)	0.30	0.8606 (0.8226-0.8985)	-0.4%
WVZ (6-month interval)	0.78 (0.69-0.88)	<0.001	0.8718 (0.8325-0.9110)	0.7%
Model 2 (mutually adjusted)			0.8842 (0.8479-0.9205)	2.0%
WAZ	0.83 (0.72-0.96)	<0.001		
WVZ (6-month interval)	0.78 (0.69-0.88)	<0.001		
Model 3 (mutually adjusted)			0.8794 (0.8426-0.9162)	1.5%
WLZ	0.77 (0.66-0.89)	<0.001		
WVZ (6-month interval)	0.75 (0.67-0.85)	<0.001		
Model 4 (mutually adjusted)			0.8655 (0.8270-0.9041)	0.1%
WAZ	0.92 (0.74-1.13)	0.40		
WLZ	0.89 (0.72-1.10)	<0.001		
Model 5 (mutually adjusted)			0.8801 (0.8435-0.9167)	1.5%
WAZ	0.98 (0.80-1.21)	0.90		
WLZ	0.78 (0.63-0.96)	0.02		
WVZ (6-month interval)	0.75 (0.67-0.85)	<0.001		

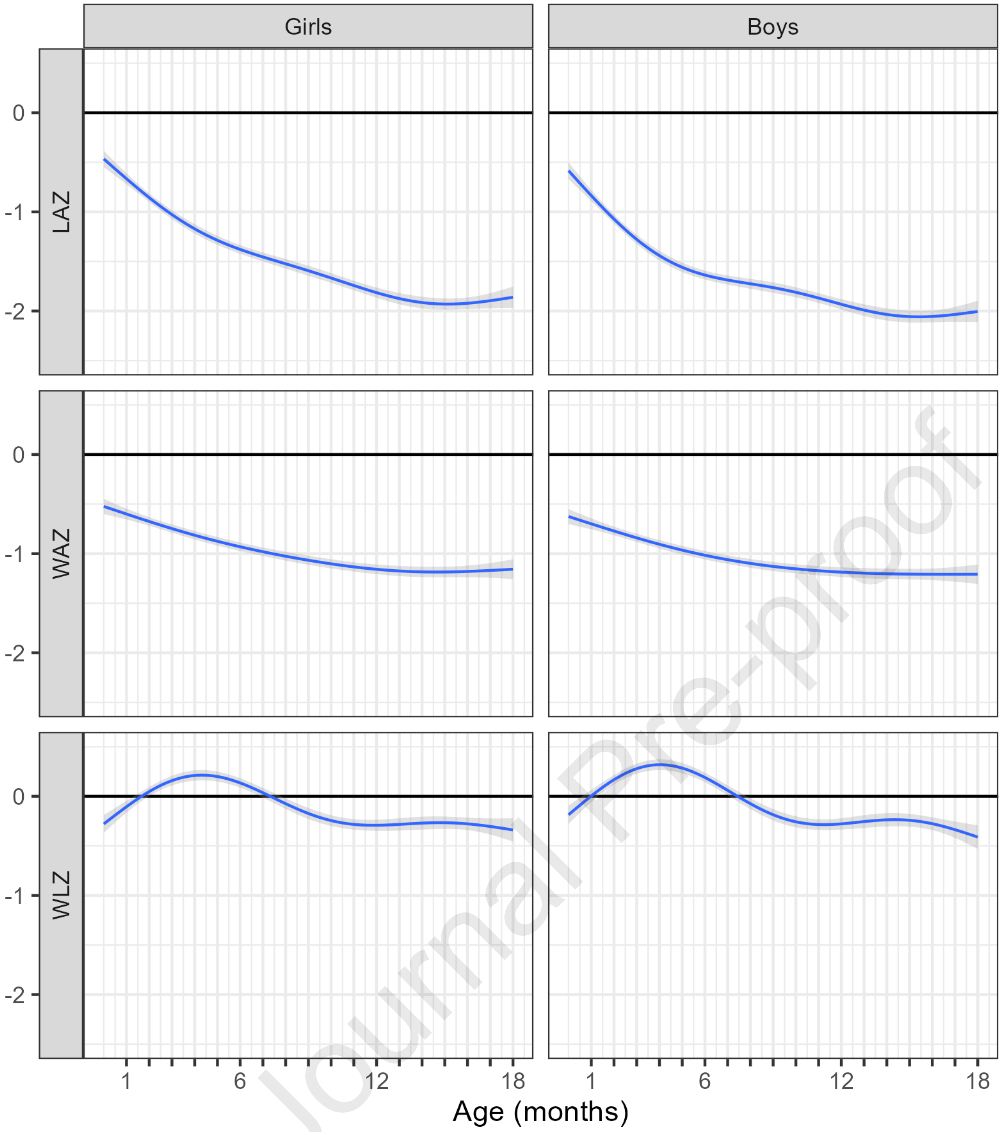
Data presented as hazard ratios (HR) with their respective 95% CI using Cox proportional models. All analyses were adjusted for age, sex, and country of origin. Total measurements: 20,385 and deaths: 98. The c-index is an indicator of risk prediction which estimates the probability of concordance between observed and predicted responses. Values close to 0.5 are equivalent to a random guess while 1.0 is equivalent to perfect prediction. WAZ: weight-for-age z-score; WVZ: Weight velocity z-score; LAZ: length-for-age z-score; BMI: body mass index.

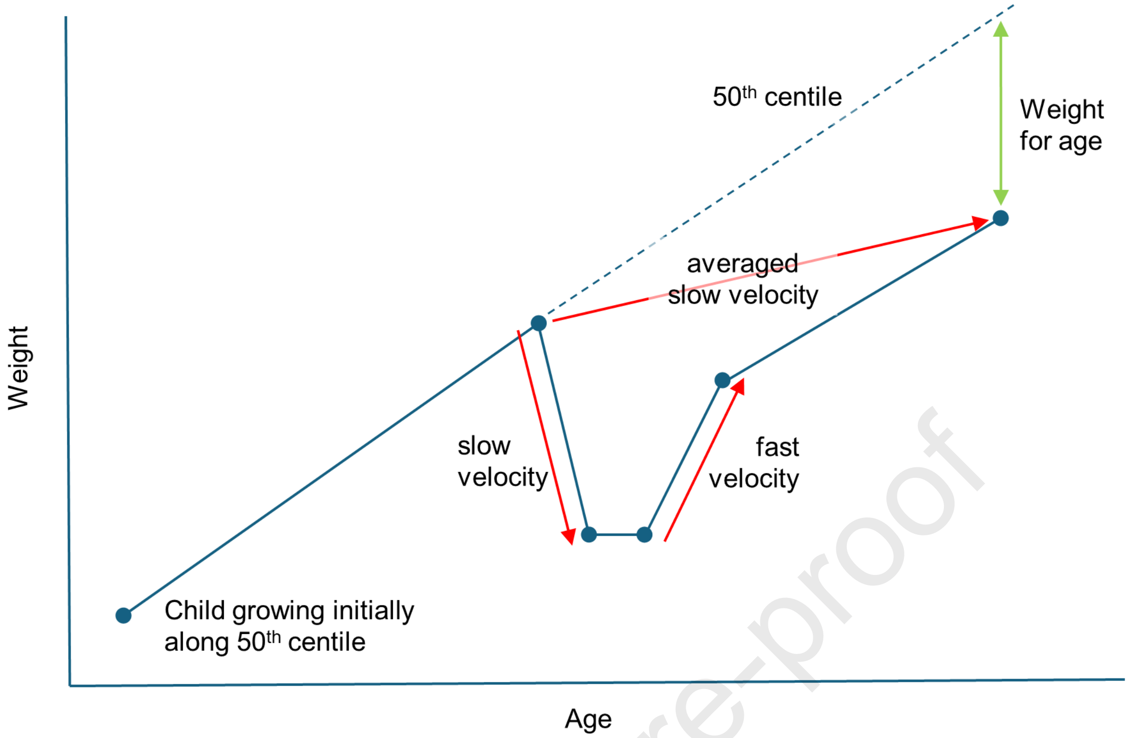
Figure Legends

Figure 1. Age trend of growth indicators by sex.

Figure 2: The challenge of assessing weight gain across an episode of weight faltering

A child showing slow, then fast velocity, averaged to a relatively slow velocity over a longer time, but with two sources of error. The last weight-for-age z score describes how much the weight deviates from the average for that age, with only one source of error


Girls
Boys
LAZ
WAZ
WLZ
0
-1
-2
1
6
12
18
Age (months)


50th centile
Weight
for age
averaged
slow velocity
Weight
slow
velocity
fast
velocity
Child growing initially
along 50th centile
Age

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: