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New analytic approaches in auxology

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Auxologists have always recognized the importance of stature growth as an indicator of child health and well-being, but recent associations between growth and health later in life have made understanding the ecology of human development more important than ever (1–4). It seems obvious that variation in stature growth may be attributed to differences in both genes and environmental exposures (5,6); however, teasing apart their relative effects and assessing interactions can be a significant challenge (6,7). Limitations in data collection and analytic methods have left many important (and often quite old) questions about growth variation (8) at least partially unresolved (5,6,9). At the same time, a number of fresh perspectives have emerged in the ecology of growth to present auxologists with new questions (7,10). It now seems apparent that novel analytic approaches will be required to address both sets of questions. Two articles, one recently published in *Pediatric Research* (11) and one appearing in this issue (ref. 12), serve to illustrate the lingering need to resolve many of the older questions as well as to provide novel analytic frameworks required to move the field forward in the coming years.

Why are the Dutch among the tallest populations in the world while the Maya remain among the shortest (11,13)? Although it would seem obvious that improved nutrition and greater access to health care must explain some of these differences, simple models of growth as the incremental accumulation of height, modulated only by better nutrition and the reduction of energetic trade-offs, do not seem entirely adequate (14,15). For example, although it is clear that improved nutrition has resulted in US-living Maya being taller than their Guatemalan counterparts, why do these Maya remain significantly shorter than the US average for their age and sex even after nearly two generations of exposure to an Americanized lifestyle (13)? It is clear that secular trends reflect shifts associated with the environmentally induced expression of genes: 100 y ago, the Dutch were among the shortest populations in Europe. The answer to why the Dutch are so much taller than the Maya is much more likely to reflect environment than genes, and only with more time will we observe how tall the Maya can potentially become. However, if simple nutritional inputs that magnify growth increments underlie these types of differences, then why do population averages in stature shift on a generation-to-generation basis in what appears to be a discrete manner, as Tanner first observed (16)? This effect produces what appears to be "catch-up" and "catch-down" growth as individuals adjust to a population level mean that shifts from generation to generation with little overlap, much as if a cohort-specific target in height were being set at the beginning of the process (ref. 16; see ref. 12 as well).

Observations of strong relationships between stature growth and maturational timing (9), as well as the curious phenomena of generation-specific target-seeking growth trajectories (16), suggest that a more complicated ecology shapes these differences. Relationships between maturation status and growth seem especially important when we consider that one of the most significant findings of life-history biology (the branch of biology that studies the ecology and evolution of the timing of life-course events including schedules of growth, fertility, mortality, and related traits; see refs. 17,18) in the past 50 y has been the observation that age at maturity is subject to powerful ecological influences that must play out in variation in growth processes (17,18). It has been suggested that the timing of maturity is shaped by developmental experiences during both *in utero* and childhood periods. Because both low birth weight and childhood psychosocial experiences appear to accelerate maturation and, at least in some cases, predict smaller adult stature (19–22), it is possible that ecological forces shaping the timing of maturation might also be driving stature differences (10,17–19). The potentially complex, but also likely very elegant, ecological dynamics underlying these relationships are forcing auxologists to consider growth within the larger biocultural context of the human life history (6,7). Traditional models of nutrition and growth, and analyses of cross-sectional data, appear poorly suited to the sometimes daunting task of disentangling these effects.

The challenges associated with making inferences about growth differences may explain why Schönbeck *et al.* (11) report that the causes of their results remain "unclear." They link their main finding—a diminishing secular increase in height between 1997 and 2009 among the Dutch—to potential trends in "environmental determinants"; however, they remain largely unable to further assess what these determinants might be or whether they represent statistically or biologically important effects. Likewise, although they note persistent regional differences in spite of what appears to be a trend toward greater

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economic similarity across these regions, they are also unable to analyze these observations in greater detail. This inability to make more definitive statements about their results does not speak to any deficiency in their work; rather, their very important findings are subject to limitations inherent in the use of cross-sectional data and standard statistical methods used in auxology.

It appears that this limitation is not unique to their study. Although these researchers are asking the right questions, the limitations of their data and statistical methodologies preclude further exposition. Methodological improvements in the use of cross-sectional data for understanding the environmental determinants of growth allometries have been recently presented (22,23); however, the answer to questions such as those posed by Schönbeck *et al.* will require both longitudinal data and appropriate statistical methods for using it. Auxologists should make no mistake: prospective longitudinal analyses—long the gold standard in epidemiology—are the most powerful tool available for answering lingering questions about the ecology of growth as well as moving the field forward to more thoroughly examine ecological and life-historical dynamics. When it comes to understanding the differences between the Dutch and the Maya, the determinants of the secular trend in stature, or how growth relates to other aspects of the human life course, novel analytics based on longitudinal data sets will be required.

In this issue of *Pediatric Research*, Aßmann and Hermanussen (12) provide precisely such a novel analytic framework. Although other methods for analyzing ecological complexity and examining causation in auxology have been presented in the forms of multilevel modeling (24,25) and applications of nonlinear dynamics (26), this article presents a compelling and straightforward framework for analyzing longitudinal growth data subject to serial autocorrelation and missing data (both important challenges in longitudinal growth studies). In summary, they propose a regression-based framework that permits direct testing of hypotheses about the dynamics of growth. Hypothesis testing may not be accomplished using simple descriptive methods such as curve fitting (27), and more complex probabilistic frameworks such as those used in multilevel modeling or models based on nonlinear dynamics suffer challenges related to interpretability (24–26). The approach of Aßmann and Hermanussen permits the analysis of individual differences in growth tempo and maturity status while facilitating hypothesis testing about ecologic effects. Using their novel method, the authors are able to establish community-level "target" effects, differences in maturational timing, and previous growth tempo as significant determinants of the growth process (see also ref. 24). The ability of the method they propose to deal with this more complex structure of growth determinants while simultaneously testing more specific ecological hypotheses has the potential to underpin significant advances in growth research. Although the Bayesian framework used in this article will be challenging for many readers of *Pediatric Research*, grasping the importance of this work will be worth the effort. If combined with greater utilization of longitudinal data sets or within the context of novel prospective studies of growth, their new approach may just be the key to answering some very old and quite persistent questions in auxology. It will also most certainly be an integral part of advancing our understanding of the relationship of growth to other aspects of the human life course.

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