# TOD cNORM summary

The TOD tests are norm-referenced, meaning that TOD raw scores can be converted to normative scores (in this case, IQ-type standard scores with a mean of 100 and a standard deviation of 15). The standard score expresses the position or location of a person’s raw score within the distribution of raw scores in the normative sample. For example, a standard score of 110 means that a person's raw score is two-thirds of a standard deviation greater than the mean raw score of normative group. Users of the TOD print materials can convert raw scores into standard scores by using the lookup tables in the Appendix. The TOD digital apps perform this conversion as part of the scoring and reporting process.

The TOD tests measure cognitive and linguistic abilities that increase with chronological age. Because of this, the TOD requires age-stratified norms (i.e., age-stratified raw-to-standard-score lookup tables). To construct these age-stratified norms, we used cNORM (Lenhard et al., 2018), a package for the R statistical platform. cNORM has two primary features:

1. It is a *continuous,* regression-based modeling process, which uses the variance of the entire normative sample to correct for age-specific distributional anomalies and sampling error.
2. It is a *distribution-free* method, meaning that the modeling process does not directly model age-group distribution parameters (e.g., mean, variance) and makes no assumptions about these parameters. As a result, cNORM can generate useful normative models, even when processing non-normally distributed input samples.

cNORM operates by modeling the *raw score* (*r*) as a function of person *location* (*l*, expressed as a percentile rank or other normative score) and the explanatory variable of age (a, expressed as a continuous age variable, or a discrete variable such as age-group membership or grade level). Age is “explanatory” in the sense that the latent ability for which *r* is an indicator increases with age, and that increase is presumably caused by the developmental changes that accompany the passage of time and increasing age. The functional relationship among these variables can be expressed as:

To create the raw-to-standard-score mapping required for clinical applications of the TOD tests, this functional relationship must be operationalized as a multiple regression equation. To determine the optimal regression equation, cNORM employs the mathematical methods of Taylor series. Strictly speaking, the Taylor series is an infinite polynomial expansion, but for practical purposes, much of the variance in the functional relationship can be estimated with a finite expansion by reducing the polynomial to the degree *k*, which is typically set at 3, 4 or 5, depending on certain characteristics of the normative data set. The Taylor series is thus simplified to a Taylor polynomial and consequently reduced to a model selection question for the following regression function:

The predictors in the regression function include all powers of age and location and their linear combinations up to power *k*. cNORM selects the most relevant predictors and estimates all constants *c* to approximate *r* with the desired precision and as few predictors as possible. Usually, regression functions with five terms or less suffice to explain a large proportion of the variance in the normative sample (i.e., *R2* ≥ .95).

The analysis proceeds in steps:

1. The normative sample is partitioned into roughly equal-sized age groups (or, alternatively, is grouped by grade levels).
2. Within these age groups, each person is assigned a percentile rank as their value for *l*.
3. Powers of *a* and *l* are computed, up to the value of k (e.g., *a*2, *a*3, . . . . , *a*k). Products of these powers are computed (e.g., *a*2*l*2, *a*2*l*3, . . . , *a*k*l*k).
4. The powers and products are entered as predictors in a best-subset regression analysis, with *r* as the outcome variable.
5. The expansion of the Taylor function is determined by estimating regression coefficients of the most relevant predictors from the regression analysis. The most parsimonious regression function, meeting predefined fit criteria, is selected.
6. The regression equation resulting from the previous step is used to determine the normative score (e.g., IQ-type standard score) associated with each possible raw score on the test, either by directly computing the raw scores associated with a normative score at a specific age, or by determining the zero-crossings of the inverse function of the regression model to retrieve the normative score corresponding to a specific raw score.

cNORM has the additional advantage of allowing the specification of a post-hoc age stratification scheme (i.e., one that is independent of the age groups that were used in the modeling process). Because the modeled relationship between age, location and raw score is a continuous function over chronological age, the raw-to-standard score mapping can be generated at any point along the age continuum, theoretically with any level of precision, even down to a single day. This permits the test developer to impose a stratification scheme on the published raw-to-standard-score lookup tables (e.g., at three-month intervals within each age year) that best suits the intended clinical application of the test.

*References*

Lenhard, W., Lenhard, A., & Gary, S. (2018). *cNORM: Continuous Norming*. Vienna: The Comprehensive R Network. https://cran.r-project.org/web/packages/cNORM/