Growth Curve Analysis:
A Hands-On Tutorial on Using Multilevel Regression to Analyze Time Course Data

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Keywords: growth curve analysis; multilevel regression; R; longitudinal data; time course data; eye tracking; individual differences.

Objectives and Scope

Growth curve analysis (multilevel regression) offers a statistical framework for analyzing longitudinal or time course data and for quantifying differences between individuals in the context of a model of the overall group effects. These methods have been known to statisticians for many years (e.g., Wishart, 1938), but they have only recently become a prominent statistical tool in the cognitive sciences. Interest in using these statistical methods to analyze cognitive science data has outpaced cognitive scientists' knowledge of how to implement them. This one-day tutorial will provide a hands-on introduction to using multilevel regression to analyze longitudinal or time course data and individual differences in the cognitive sciences. The focus will be on practical aspects of implementation and common pitfalls, rather than statistical theory.

The tutorial will begin with the challenges of time course data, focusing on why traditional methods such as bin-by-bin *t*-tests and repeated-measures ANOVA are sub-optimal. It will then describe how growth curve analysis (GCA) addresses those challenges and demonstrate how to use GCA to analyze simple linear data, non-linear data, and categorical outcome data (using logistic and quasi-logistic GCA). The final section will focus on using GCA to quantify and analyze individual differences. Throughout, example data sets will be provided for hands-on exercises that will give tutorial participants practice implementing the analyses, interpreting the results, and plotting data with model fits. There will also be time for tutorial participants to work on analyzing their own data with the instructor's support.

Relevance to Cognitive Science

From learning and forgetting curves to studies of cognitive development, time course or longitudinal data play a critical role in cognitive science. Cognitive processes unfold and develop over time and understanding the dynamic time course of these processes is central to understanding cognition. As experimental research methods have developed, cognitive science has acquired more and more techniques that produce a time-ordered series of observations for each participant (eye tracking, mouse/motion tracking, electroencephalography, etc.). However, the statistical methods used by cognitive scientists to analyze these data have not kept pace. Too often repeated-measures ANOVA or bin-by-bin *t*-tests are used despite well-known problems with applying these methods to time course data. Growth curve analysis offers a way to model continuous effects of time and so capture critical time course patterns in longitudinal data.

Foundational research in cognitive science examined individual differences; from cognitive deficits in neurological disorders to superior cognitive performance by chess masters and mnemonists, individual differences have shed a unique light on cognition. Even (co-)variation within a population of college students can reveal aspects of the cognitive processes involved. However, the typical statistical methods used by cognitive scientists do not offer a way to quantify or analyze individual deviations from an overall group pattern. Growth curve analysis provides a statistical framework for quantifying and analyzing individual differences in the context of a model of the overall group effects, thus adding a critical analytical tool for advancing theories of cognitive function.

Target Audience and Pre-requisites

This tutorial will provide a practical, hands-on introduction to growth curve analysis, so the primary target audience is scientists who are actively involved in analyzing time course data: graduate students, post-docs, senior scientists (faculty), and advanced undergraduates.

The tutorial will be conducted in R using the lme4 package for fitting GCA models and will include an introduction to using the ggplot2 package for plotting data and model fits. Tutorial participants are expected to have basic familiarity with R, but no specific knowledge of the ggplot2 or lme4 packages is required. For those not yet familiar with R, there are many good introductory tutorials and books available (a list of recommended ones is available at: http://www.danmirman.org/r-resources).

The tutorial will include hands-on exercises and an opportunity to work on participants' own data, so participants are encouraged to bring their laptops with R installed (http://cran.r-project.org/) along with the lme4 and ggplot2 packages. RStudio (http://www.rstudio.com/) is a full-featured cross-platform integrated development environment for R that makes R more user-friendly. It is highly recommended, but not required for this tutorial. Workshop materi-

als, including example data sets can be found at http://www.danmirman.org/gca.

Instructor

Daniel Mirman is an Assistant Professor of Psychology at Drexel University. He completed Ph.D. training in 2005 at Carnegie Mellon University and post-doctoral training at University of Connecticut and Haskins Laboratories. From 2009 to 2013 he was an Institute Scientist at the Moss Rehabilitation Research Institute before assuming his current position at Drexel University. His NIH-funded research program uses behavioral, eye-tracking, cognitive neuropsychology, and computational modeling methods to understand the basic mechanisms of cognitive and perceptual processing, particularly in the domain of spoken language.

In addition to his empirical and theoretical research, he has worked to facilitate adoption of growth curve analysis through publications (Mirman, Magnuson, & Dixon, 2008) and informal and formal tutorials. His recent book (Mirman, 2014) provides an accessible guide to implementing growth curve analysis for behavioral scientists. He has previously taught tutorials on growth curve analysis at University of Pennsylvania, Northwestern University, University of California – Merced, and University of Wisconsin – Madison. This tutorial will focus on analyzing time course data in the cognitive sciences, using examples from cognitive science and addressing common pitfalls that arise with these data.

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Tutorial Structure

The tutorial will be delivered using a combination of lecture, demonstrations, and hands-on exercises. A detailed schedule is provided in Table 1.

References

Mirman, D. (2014). *Growth Curve Analysis and Visualization Using R*. Florida, USA: Chapman & Hall/CRC.

Mirman, D., Dixon, J. A., & Magnuson, J. S. (2008). Statistical and computational models of the visual world paradigm: Growth curves and individual differences. *Journal of Memory and Language*, *59*(4), 475–494. doi:10.1016/j.jml.2007.11.006

Wishart, J. (1938). Growth-rate determinations in nutrition studies with the bacon pig, and their analysis. *Biometrika, 30*(1/2), 16-28.

Table 1: Detailed schedule.

Time	Content
9am – 10am	Introduction, challenges of time course data, GCA basics
10am – 10:30am	Break, hands-on exercise
10:30 – Noon	Modeling nonlinear change, plotting model fits, within-subject effects
Noon – 1:30pm	Lunch break, hands-on exercise
1:30pm – 2:30pm	Logistic and quasi-logistic GCA
2:30pm – 3pm	Break, hands-on exercise
3pm – 4pm	Quantifying and analyzing individual differences
4pm – 5:30pm	Hands-on exercises and time for participants to try analyzing their own data with instructor support