Digital Module 16: Longitudinal Data Analysis

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Module Overview

In this digital ITEMS module, Dr. Jeffrey Harring and Ms. Tessa Johnson introduce the linear mixed effects (LME) model as a flexible general framework for simultaneously modeling continuous repeated measures data with a scientifically-defensible function that adequately summarizes both individual change as well as the average response. The module begins with a non-technical overview of longitudinal data analyses drawing distinctions with cross-sectional analyses in terms of research questions to be addressed. Nuances of longitudinal designs, timing of measurements, and the real possibility of missing data are then discussed. The three interconnected components of the LME model: (1) a model for individual and mean response profiles, (2) a model to characterize the covariation among the time-specific residuals, and (3) a set of models that summarize the extent that individual coefficients vary, are discussed in the context of the set of activities comprising an analysis. Finally, they demonstrate how to estimate the linear mixed effects model within an open-source environment (R). The digital module contains sample R code, diagnostic quiz questions, hands-on activities in R, curated resources, and a glossary.

Key words: fixed effect, linear mixed effects models, longitudinal data analysis, multilevel models, population-average, random effect, regression, subject-specific, trajectory

Prerequisite Knowledge

This ITEMS module assumes no prior knowledge of longitudinal models or methods. However, to get the most out of this module, it might be beneficial to have a basic understanding of:

- foundational statistical concepts such as hypothesis testing and p-values
- how to explore and summarize variables numerically and graphically—understand the principles of exploratory data analysis
- multiple linear regression as the module will build from this foundation
- the general linear model as it pertains to repeated measures ANOVA
- R statistical software would help enhance the user's experience with the module—in particular the "real data analytic" section

Learning Objectives

Upon completion of this ITEMS module, learners should be able to:

- design research questions that can be answered with linear mixed models for longitudinal data
- understand design features of longitudinal data including data collection protocols, missing data, and timing of measurements
- explore and summarize longitudinal data both numerically and graphically
- understand the three interconnected pieces of a basic linear mixed model
- write out using statistical notation the linear mixed models and its distributional assumptions
- run a linear mixed model analysis using the R statistical software

Module Structure

The digital module is divided into the following sections, which can be reviewed sequentially or independently [*approximate completion times in parentheses*].

- Section 1: Overview [*15 Minutes*]
- Section 2: Longitudinal Design and Data Considerations [*15 Minutes*]
- Section 3: Linear Mixed Effects Model [*15 Minutes*]
- Section 4: Linear Mixed Effects Modeling Analysis [*25 Minutes*]
- Section 5: Self-Guided Data Analytic Activity [*25 Minutes*]

In the portal site, you can also find a video version of the core content as well as a handout with all core slides along with other materials.

Module Components

This ITEMS module includes the following components, which are delivered within a web-delivered unified design shell that is compatible across platforms (i.e., laptops, desktops, tablets, cell phones) and was created with modern course development software (*Articulate 360*):

- integrated content slides that provide a structured walk-through of the content with suitable voice-over
- embedded didactic videos to demonstrate software implementations
- interactive quiz questions
- data activity sample SAS code and annotated solutions
- glossary of key terms
- supplementary digital resources

Additional materials may be added over time so check back periodically!

Instructors

Jeffrey R. Harring, *Professor at University of Maryland, College Park*

Jeff is a Professor in the Measurement, Statistics and Evaluation Program within the Department of Human Development and Quantitative Methodology at the University of Maryland, College Park. There, he teaches introductory and intermediate graduate level statistics courses and advanced quantitative methods seminars in longitudinal data analysis, mixture modeling, simulation design and statistical computing. Jeff has taught several multi-day workshops on the application of longitudinal methods using R and SAS statistical software most recently at the National Center of Educational Statistics (NCES) in Washington D.C. Prior to joining the program faculty in the fall of 2006, Jeff received an M.S. degree in Statistics and completed his Ph.D. in the Quantitative Methods in Education from the University of Minnesota. Before that, Jeff taught high school mathematics for 12 years. He has published nearly 100 articles and book chapters, co-edited three volumes and co-authored a book. His research focuses on linear and nonlinear models for repeated measures data, structural equation models, finite mixtures of both linear and nonlinear growth models and extensions of these methods to multilevel data structures.

Tessa L. Johnson, *Doctoral Candidate at University of Maryland, College Park*

Tessa is a Ph.D. candidate in the Measurement, Statistics and Evaluation Program within the Department of Human Development and Quantitative Methodology at the University of Maryland, College Park. She received her Master of Science in Educational Research from Georgia State University. Tessa currently serves as a project coordinator for the Synthetic Data Project (SDP) of the Maryland Longitudinal Data System Center, an Institute of Education Sciences (IES) funded project aimed at assessing the feasibility of and implementing a system for synthesizing statewide longitudinal data in order to increase data access for researchers and policy analysts while minimizing risk of data disclosure. For the SDP, Tessa conducts research on the feasibility of reproducing nested data structures in longitudinal synthetization models. Outside her work with the SDP, Tessa's research has centered around creating and improving statistical methods for analyzing complex data structures in longitudinal contexts. This includes modeling time as an outcome in latent growth models, accounting for similarities among schools when modeling student mobility in longitudinal studies, and exploring the development of ensembles of social networks in the classroom over time.

Instructional Design Team

André A. Rupp, *Mindful Measurement*

André is the co-author and co-editor of two award-winning interdisciplinary books entitled *Diagnostic Measurement: Theory, Methods, and Applications* (2010) and *The Handbook of Cognition and Assessment: Frameworks, Methodologies, and Applications* (2016) and has just published the *Handbook of Automated Scoring: Theory into Practice* (2020). His research synthesis- and framework-oriented work has appeared in a wide variety of prestigious peer-reviewed journals. Among other things, he is passionate about improving processes for interdisciplinary collaborations during the development and implementation of scoring solutions for digitally-delivered assessments. Consequently, he is very excited to serve as the associate editor / lead instructional designer of the ITEMS portal for NCME whose mission is to provide free digital resources to support self-directed learning and professional development.

Jonathan Lehrfeld, *Psychometrician at Educational Testing Service (ETS)*

Jon graduated from Fordham University in 2016 with a Ph.D. in psychometrics and quantitative psychology, where his dissertation focused on integrating propensity score methods with structural equation modeling. After graduating, he worked at the Council for Aid to Education (CAE) for three years, serving as their psychometrician and Associate Director of Measurement Science. While at CAE, his operational and research work focused on practical problems in low-stakes testing. He most recently joined ETS where he currently works as a psychometrician on a large-scale state assessment team.

Xi Lu, *Doctoral Candidate at Florida State University*

Xi is a doctoral candidate in the Instructional Systems and Learning Technologies program at Florida State University. Her current research interest focuses on designing and developing optimal learning supports to facilitate STEM learning in digital interactive environments. She also works as a research assistant with Dr. Val Shute on an NSF project targeted at designing various learning supports for a 2D physics game called *Physics Playground* to help middle school kids learn physics. Before coming to FSU, Xi taught Chinese for six years in Monterey Bay, California.
