

# Contents

## **1 • Introduction**

1

- Uses of Confirmatory Factor Analysis / 1
  - Psychometric Evaluation of Test Instruments* / 1
  - Construct Validation* / 2
  - Method Effects* / 3
  - Measurement Invariance Evaluation* / 4
- Why a Book on CFA? / 5
- Coverage of the Book / 6
- Other Considerations / 8
- Summary / 11

## **2 • The Common Factor Model and Exploratory Factor Analysis**

12

- Overview of the Common Factor Model / 12
- Procedures of EFA / 20
  - Factor Extraction* / 21
  - Factor Selection* / 23
  - Factor Rotation* / 30
  - Factor Scores* / 36
- Summary / 37

## **3 • Introduction to CFA**

40

- Similarities and Differences of EFA and CFA / 40
  - Common Factor Model* / 40
  - Standardized and Unstandardized Solutions* / 41
  - Indicator Cross-Loadings/Model Parsimony* / 42
  - Unique Variances* / 46
  - Model Comparison* / 47

Purposes and Advantages of CFA /	49
Parameters of a CFA Model /	53
Fundamental Equations of a CFA Model /	59
CFA Model Identification /	62
<i>Scaling the Latent Variable /</i>	62
<i>Statistical Identification /</i>	63
<i>Guidelines for Model Identification /</i>	71
Estimation of CFA Model Parameters /	72
<i>Illustration /</i>	76
Descriptive Goodness-of-Fit Indices /	81
<i>Absolute Fit /</i>	82
<i>Parsimony Correction /</i>	83
<i>Comparative Fit /</i>	84
<i>Guidelines for Interpreting Goodness-of-Fit Indices /</i>	86
Summary /	88
Appendix 3.1. Communalities, Model-Implied Correlations, and Factor Correlations in EFA and CFA /	90
Appendix 3.2. Obtaining a Solution for a Just-Identified Factor Model /	93
Appendix 3.3. Hand Calculation of $F_{ML}$ for the Figure 3.8 Path Model /	96

## 4 • Specification and Interpretation of CFA Models

103

An Applied Example of a CFA Measurement Model /	103
Model Specification /	106
<i>Substantive Justification /</i>	106
<i>Defining the Metric of Latent Variables /</i>	106
Data Screening and Selection of the Fitting Function /	107
Running the CFA Analysis /	108
Model Evaluation /	113
<i>Overall Goodness of Fit /</i>	113
<i>Localized Areas of Strain /</i>	114
<i>Residuals /</i>	115
<i>Modification Indices /</i>	119
<i>Unnecessary Parameters /</i>	124
<i>Interpretability, Size, and Statistical Significance of the Parameter         Estimates /</i>	126
Interpretation and Calculation of CFA Model Parameter Estimates /	132
CFA Models with Single Indicators /	138
Reporting a CFA Study /	144
Summary /	148
Appendix 4.1. Model Identification Affects the Standard Errors of the Parameter Estimates /	150
Appendix 4.2. Goodness of Model Fit Does Not Ensure Meaningful Parameter Estimates /	153
Appendix 4.3. Example Report of the Two-Factor CFA Model of Neuroticism and Extraversion /	155

<b>5 • CFA Model Revision and Comparison</b>	157
Goals of Model Respecification / 157	
Sources of Poor-Fitting CFA Solutions / 159	
<i>Number of Factors / 159</i>	
<i>Indicators and Factor Loadings / 167</i>	
<i>Correlated Errors / 181</i>	
<i>Improper Solutions and Nonpositive Definite Matrices / 187</i>	
EFA in the CFA Framework / 193	
Model Identification Revisited / 202	
Equivalent CFA Solutions / 203	
Summary / 209	
<b>6 • CFA of Multitrait–Multimethod Matrices</b>	212
Correlated versus Random Measurement Error Revisited / 212	
The Multitrait–Multimethod Matrix / 213	
CFA Approaches to Analyzing the MTMM Matrix / 217	
<i>Correlated Methods Models / 218</i>	
<i>Correlated Uniqueness Models / 220</i>	
Advantages and Disadvantages of Correlated Methods and	
Correlated Uniqueness Models / 227	
Other CFA Parameterizations of MTMM Data / 229	
Consequences of Not Modeling Method Variance and	
Measurement Error / 231	
Summary / 233	
<b>7 • CFA with Equality Constraints, Multiple Groups, and Mean Structures</b>	236
Overview of Equality Constraints / 237	
Equality Constraints within a Single Group / 238	
<i>Congeneric, Tau-Equivalent, and Parallel Indicators / 238</i>	
<i>Longitudinal Measurement Invariance / 252</i>	
CFA in Multiple Groups / 266	
<i>Overview of Multiple-Groups Solutions / 266</i>	
<i>Multiple-Groups CFA / 268</i>	
<i>Selected Issues in Single- and Multiple-Groups CFA Invariance</i>	
<i>Evaluation / 299</i>	
<i>MIMIC Models (CFA with Covariates) / 304</i>	
Summary / 316	
Appendix 7.1. Reproduction of the Observed Variance–Covariance Matrix with	
Tau-Equivalent Indicators of Auditory Memory / 318	

<b>8 • Other Types of CFA Models: Higher-Order Factor Analysis, Scale Reliability Evaluation, and Formative Indicators</b>	320
<hr/>	
Higher-Order Factor Analysis / 320	
<i>Second-Order Factor Analysis</i> / 322	
<i>Schmid–Leiman Transformation</i> / 334	
Scale Reliability Estimation / 337	
<i>Point Estimation of Scale Reliability</i> / 337	
<i>Standard Error and Interval Estimation of Scale Reliability</i> / 345	
Models with Formative Indicators / 351	
Summary / 362	
<b>9 • Data Issues in CFA: Missing, Non-Normal, and Categorical Data</b>	363
<hr/>	
CFA with Missing Data / 363	
<i>Mechanisms of Missing Data</i> / 364	
<i>Conventional Approaches to Missing Data</i> / 365	
<i>Recommended Missing Data Strategies</i> / 367	
CFA with Non-Normal or Categorical Data / 378	
<i>Non-Normal, Continuous Data</i> / 379	
<i>Categorical Data</i> / 387	
<i>Other Potential Remedies for Indicator Non-Normality</i> / 404	
Summary / 410	
<b>10 • Statistical Power and Sample Size</b>	412
<hr/>	
Overview / 412	
Satorra–Saris Method / 413	
Monte Carlo Approach / 420	
Summary and Future Directions in CFA / 429	
Appendix 10.1. Monte Carlo Simulation in Greater Depth:	
Data Generation / 434	
<b>References</b>	439
<b>Author Index</b>	455
<b>Subject Index</b>	459