

THIRD EDITION

Jum C. Nunnally

Late Professor of Psychology
Vanderbilt University

Ira H. Bernstein

Professor of Psychology
The University of Texas at Arlington

McGRAW-HILL, INC.

New York St. Louis San Francisco Auckland Bogota
Caracas Lisbon London Madrid Mexico City Milan Montreal
New Delhi San Juan Singapore Sydney Tokyo Toronto

CONTENTS

PREFACE

PART 1	INTRODUCTION	1
1	Introduction	3
	CHAPTER OVERVIEW	3
	MEASUREMENT IN SCIENCE	3
	What Is "Meaningful" and "Useful"?	
	ADVANTAGES OF STANDARDIZED MEASURES	6
	Objectivity / Quantification / Communication / Economy / Scientific Generalization	
	MEASUREMENT AND MATHEMATICS	8
	Measurement and Statistics	
	MEASUREMENT SCALES	11
	Nominal scales / Ordinal scales / Interval scales / Ratio Scales / Other Scales / Invariance	
	DECISIONS ABOUT MEASUREMENT SCALES	20
1	Ostensive Characteristics / Consequences of Assumptions / Convention /Classification as Measurement	
	RECENT TRENDS IN MEASUREMENT	27
	The Impact of Computers / Closed versus Open-Form Solutions / Computer Simulation	
	SUMMARY	29
	SUGGESTED ADDITIONAL READINGS	30
PART 2	STATISTICAL FOUNDATIONS	31
2	Traditional Approaches To Scaling	33
	CHAPTER OVERVIEW	33

CONTENTS

DATA MATRICES	34
More Complex Organizations / "Holes" in the Matrix (Missing Data)	
EVALUATION OF MODELS	36
Scaling Stimuli versus Scaling People	
A BRIEF INTRODUCTION TO PSYCHOPHYSICS	39
Psychophysical Methods / Absolute Thresholds / Simulating a Threshold / Difference Thresholds / The Weber Fraction, Fechner's Law, and Psychophysical Scaling / Direct Psychophysics and the Plateau-Stevens Tradition / The Fullerton-Cattell Law / Signal Detection Theory and Modern Psychophysics	
TYPES OF STIMULI AND RESPONSES	50
Judgments versus Sentiments / Absolute versus Comparative Responses / Preferences versus Similarity Responses / Specified versus Unspecified Attributes	
METHODS FOR CONVERTING RESPONSES TO STIMULUS SCALES	53
Ordinal Methods / Interval Methods / Ratio Methods	
MODELS FOR SCALING STIMULI	55
Direct (Subjective Estimate) Models / Indirect (Discriminant) Models / Simulating Thurstone Scaling / A Comparison of the Two Simulations / The Logistic Distribution and Luce's Choice Theory / Averages as Scale Values / Checks and Balances / Multi-item Measures / Item Trace Lines (Item Characteristics Curves) / Difficulty and Discrimination	
DETERMINISTIC MODELS FOR SCALING PEOPLE	71
The Guttman Scale / Evaluation of the Guttman Scale	
PROBABILISTIC MODELS FOR SCALING PEOPLE	75
Nonmonotone Models / Monotone Models with Specified Distribution Forms / Monotone Models with Unspecified Distribution Forms	
SUMMARY	81
SUGGESTED ADDITIONAL READINGS	82
3 Validity	83
CHAPTER OVERVIEW	83
GENERAL CONSIDERATIONS	84
CONSTRUCT VALIDITY	84
Domain of Observables / Relations among Observables / Relations among Constructs / Campbell and Fiske's Contribution to Construct Validation	
PREDICTIVE VALIDITY	94
The Temporal Relation between Predictor and Criterion / The Criterion Problem / Other Problems in Prediction / The "Composite Criterion" / Validity Coefficients / Validity Generalization / Meta-analysis	
CONTENT VALIDITY	101
EXPLICATION OF CONSTRUCTS	104

	Changing Substantive Theories versus Changing Measurement Theories / A Commonsense Point of View	
	OTHER ISSUES CONCERNING VALIDITY	108
	Relations among the Three Types of Validity / Other Names / The Place of Factor Analysis	
	SUMMARY	112
	SUGGESTED ADDITIONAL READINGS	113
4	Elements of Statistical Description and Estimation	114
	CHAPTER OVERVIEW	114
	CONTINUOUS VERSUS DISCRETE (CATEGORICAL) VARIABLES	115
	VARIANCE	116
	Transformations of Distributions	
	CORRELATION AND COVARIANCE AS CONCEPTS	120
	THE PEARSON PRODUCT-MOMENT CORRELATION	120
	The Meaning of Pearson Product-Moment Correlation / Computer Applications / Covariance / Other Measures of Linear Relation / Three Special Cases	
	ESTIMATES OF r	125
	Biserial $r(r_{Us})$ / Tetrachoric Correlation (r_{tet}) and Related Estimates	
	PEARSON r VERSUS ESTIMATES OF PEARSON r	127
	Some Related Issues in Categorization	
	ASSUMPTIONS UNDERLYING r	129
	FACTORS INFLUENCING r	130
	Restriction of Range / Distribution Form	
	A UNIVERSAL MEASURE OF RELATIONSHIP	135
	PREDICTION, REGRESSION, AND STRUCTURAL EQUATIONS	139
	Regression / Regression Based upon Raw Scores / The Standard Error of Estimate / Partitioning of Variance / Structural Equations	
	STATISTICAL ESTIMATION AND STATISTICAL DECISION THEORY	147
	Generalized Least-Squares Estimation / Maximum Likelihood Estimation / Maximum Likelihood and the Testing of Hierarchical Models / Bayesian Estimation / The Method of Moments / Equal Weighting (The "It Don't Make No Nevermind Principle") / Properties of Estimators	
	SUMMARY	156
	SUGGESTED ADDITIONAL READINGS	158
5	Linear Combinations, Partial Correlation, Multiple Correlation, and Multiple Regression	159
	CHAPTER OVERVIEW	159
	VARIANCES OF LINEAR COMBINATIONS	160
	Variance of a Weighted Sum / Variance of a Sum of Standard Scores /	

	Variance of Sums of Dichotomous Distributions / Numerical Examples	
	CHARACTERISTICS OF SCORE DISTRIBUTIONS	166
	Variances / Distribution Shape	
	COVARIANCE OF LINEAR COMBINATIONS	171
	Correlation of Linear Combinations / Numerical Example	
	PARTIAL CORRELATION	175
	An Example of Partialling / Higher-Order Partialling / Another Form of Partialling	
	MULTIPLE CORRELATION AND MULTIPLE REGRESSION	182
	The Two-Predictor Case / Numerical Example / The General Case / Testing the Significance of t and Increments in R / Determinants of R / Categorical Predictors / Multicollinearity / Predictor Importance	
	SELECTION AND ALTERNATIVE WEIGHTINGS OF PREDICTORS	193
	Stepwise Inclusion of Predictors / AN Possible Subsets Approaches / Hierarchical Inclusion of Variables / Combining Strategies / Moderated Multiple Regression / Variable Weighting	
	RELATED TOPICS	203
	The Analysis of Covariance / Nonlinear Relations / Residual Analysis / Canonical Analysis	
	SUMMARY	205
	SUGGESTED ADDITIONAL READINGS	208
	PART 3 CONSTRUCTION OF MULTI-ITEM MEASURES	209
6	The Theory of Measurement Error	211
	CHAPTER OVERVIEW	211
	THE CONCEPT OF MEASUREMENT ERROR	212
	ONE FORM OF CLASSICAL TEST THEORY	215
	THE DOMAIN-SAMPLING MODEL	216
1	Multi-item Measures / Estimates of Reliability / The Importance of the Reliability Coefficient	
	THE MODEL OF PARALLEL TESTS	223
	PERSPECTIVES ON THE TWO MODELS	226
	Factorial Composition	
	PRECISION OF RELIABILITY ESTIMATES	228
	Variances of Items	
	FURTHER DEDUCTIONS FROM THE DOMAIN-SAMPLING MODEL	230
	Test Length / The Reliability of an Item Sample and Coefficient Alpha / Numerical Example / Variance of True and Error Scores / Estimation of True Scores / The Standard Error of Measurement / Attenuation	

ALTERNATIVE MODELS	241
Factorial Domain-Sampling Model / The Binomial Model	
RELIABILITY AS STABILITY OVER TIME	243
Difference Scores / One Other Consideration	
SUMMARY	246
SUGGESTED ADDITIONAL READINGS	247
7 The Assessment of Reliability	248
CHAPTER OVERVIEW	248
SOURCES OF ERROR	249
Variation within a Test / Variation between Tests	
ESTIMATION OF RELIABILITY	251
Internal Consistency / Alternative Forms / Other Estimates of Reliability / Long-Range Stability	
USES OF THE RELIABILITY COEFFICIENT	256
Corrections for Attenuation / Confidence Intervals / Effect of Dispersion on Reliability	
MAKING MEASURES RELIABLE	262
Test Length / Standards of Reliability / Limitations on the Reliability Coefficient's Utility	
RELIABILITY OF LINEAR COMBINATIONS	266
Negative Elements / Weighted Sums / Principles Concerning the Reliability of Linear Combinations	
AN ANALYSIS OF VARIANCE APPROACH TO RELIABILITY	274
Some Basic Concepts / Application to the Study of Reliability	
GENERALIZABILITY THEORY	279
Basic Concepts / Generalizability Studies and Decision Studies / A Single Facet Design / Theoretical Considerations / Applying the Results of a Single Facet <i>G</i> Study to a <i>D</i> Study / A Fixed-Facet Design / Higher-Order Designs	
SUMMARY	290
SUGGESTED ADDITIONAL READINGS	292
8 Construction of Conventional Tests	293
CHAPTER OVERVIEW	293
CONSTRUCTION OF TESTS DESIGNED FOR CONTENT VALIDATION	295
The Domain of Content and Test Plan / Test Items / Test Length / Sample of Subjects / Item Analysis / Item Selection / Norms / The Role of External Correlates	
CONSTRUCTION OF TESTS DESIGNED FOR CONSTRUCT VALIDATION	310
The Hypothesis and Domain of Content / Content Homogeneity / Methodological Heterogeneity / Relations among Measures and Constructs / The Role of Factor Analysis / Item Analysis and Selection / The Inadequacy of Rational Approaches to Test	

Construction / The Inadequacy of Empirical (Criterion-Oriented)	
Approaches to Test Construction / Norms / Applying the Measure /	
Some Examples of Constructs in the Abilities Area	
CONSTRUCTION OF TESTS DESIGNED FOR PREDICTIVE	
VALIDATION	324
Item Analysis, Item Selection, and Norms	
PROBLEMS UNIQUE TO CERTAIN TESTING SITUATIONS	326
Reversing the Direction of Keying / Unipolar versus Bipolar Attributes /	
Discrimination at a Point / Equidiscriminating Tests / Weighting of	
Items / Taking Advantage of Chance	
SUMMARY	• 334
SUGGESTED ADDITIONAL READINGS	337
9 Special Problems in Classical Test Theory	338
CHAPTER OVERVIEW	338
GUESSING	340
The Blind Guessing Model and Abbott's Formula / Effects of Guessing	
on Test Parameters / The Accuracy of the Correction for Blind	
Guessing/Sophisticated Guessing Models / Practical	
Considerations / Using the Model to Estimate Test Parameters /	
Multiple-Choice versus Short Answer Tests	
SPEED TESTS	348
The Internal Structure of Speed Tests / The Item Pool / Measurement	
of Reliability / Factor Composition / Variables Relating to Speed /	
Statistical Effects of Time Limits / One-Trial Measures of the Effects	
of Time Limits / Correction for Guessing in Speed Tests / Timed-	
Power Tests / Speed-Difficulty Tests / Factors Measured by Speed	
and Power Tests / Implications	
ADVERSE IMPACT, IMPROPER DISCRIMINATION, TEST	
BIAS, AND DISPARITY	357
Definitions of Bias / Disparity and Bias / Test Bias, Regression, and	
the Clean/ Rule / Applying Linear Regression to Salary Disputes /	
Reverse Regression / Residual Analysis / Simpson's Paradox	
Revisited / Bias in Content-Validated Measures / Barriers and	
Cutoffs / Selection Fairness and Quotas / Pooled versus Separate	
Group Norms	
HALO EFFECTS	373
Traditional Measures of Halo / Recent Developments in the Study of	
Halo	
RESPONSE BIASES AND RESPONSE STYLES	376
Sources of Bias / Changes in Test Scores as Personality Changes /	
Carelessness and Confusion / The Role of Social Desirability /	
Other Proposed Stylistic Variables	

MULTISCALE TESTS	386
Item Overlap	
SUMMARY	388
SUGGESTED ADDITIONAL READINGS	392
10 Recent Developments in Test Theory	393
CHAPTER OVERVIEW	393
ITEM RESPONSE THEORY	394
Conditional Independence / One-Parameter Models / Two-Parameter Models / Three-Parameter Models / Item and Test Information / The Bock Nominal Model / The Samejima Model for Graded (Ordinal) Responses / A Nonparametric Approach / Other IRT Models / Applications to Nonstandard Testing Conditions / Scoring Algorithms	
DIFFERENTIAL ITEM FUNCTIONING (ITEM BIAS)	416
A Substantive Example / A Simulated Example / Differential Alternative Functioning / IRT Approaches to Assessing DIF / Alternative IRT Approaches / Classical Approaches to Assessing DIF / Content Bias	
TAILORED TESTS AND COMPUTERIZED ADAPTIVE TESTING	428
Tailored Testing and Psychophysical Thresholds / Applying the Staircase Principle to Psychometrics / Flexilevel Tests / More Complex Forms of Tailored Testing / Perspectives on Tailored Tests	
COMMENTARY ON IRT	433
ACHIEVEMENT TESTS FOR MASTERY LEARNING	435
Nature of Mastery Learning / Test Construction / Definition of "Mastery" / Practical Problems	
SUMMARY	438
SUGGESTED ADDITIONAL READINGS	442
 PART 4 FACTOR ANALYSIS	 445
 11 Factor Analysis I: The General Model and Variance	
Condensation	447
CHAPTER OVERVIEW	447
USES OF FACTOR ANALYSIS	449
Factors as Groupings of Variables / Exploratory and Confirmatory Analysis / Factor Analysis and Scientific Generalization / Variable and Subject Selection	
BASIC CONCEPTS	454
The General Factor Model / The Unit of Measurement / Estimating	

	Correlations / Structure Elements / Successive versus Simultaneous Factoring / Geometric and Algebraic Interpretations / Components of Variance / Types of Factors	
	CONDENSING VARIANCE IN EXPLORATORY FACTOR ANALYSIS	468
	The Role of the Correlation Matrix / Properties of a Factor Solution	
	CENTROID CONDENSATION	472
	PRINCIPAL COMPONENT AND PRINCIPAL AXIS CONDENSATION	473
	Principal Components / Mathematical Properties of Principal Components / Principal Axis Solutions	
	MAXIMUM LIKELIHOOD AND RELATED FORMS OF CONDENSATION	477
	• Usefulness of ML Factoring / Variants on ML Factoring	
	OTHER METHODS OF CONDENSATION	481
	DETERMINING THE NUMBER OF FACTORS	482
	Consequences of Choosing a Given Number of Factors	
	CAUSAL INDICATORS	484
	SUMMARY	485
	SUGGESTED ADDITIONAL READINGS	490
12	Exploratory Factor Analysis II: Rotation and Other Topics	491
	CHAPTER OVERVIEW	491
	FACTOR ROTATION	493
	Geometric Analogy / Visual Rotation / Further Mathematics of Rotation / Oblique Rotations / Simple and "Simpler" Structures / Reference Vectors	
	ANALYTIC ROTATIONS	505
	Quartimax / Varimax / Promax	
	ESTIMATION OF FACTOR SCORES	507
	Practical Considerations in Obtaining Factor Scores	
	RELATIONS AMONG THE VARIOUS MATRICES	512
	THE COMMON FACTOR MODEL	514
	The Problem of Communality Estimation / Factorable Matrices / Matrix Rank / Unities as Communality Estimates / Communalities Derived from Hypotheses / Statistical Criteria of Rank / Iteration / Squared Multiple Correlations / Reliability Coefficients / Direct Estimation / Some Major Differences between Component and Common Factor Solutions / Some Conceptual Problems with the Common Factor Model / Effects of Number of Variables and Average Correlation upon the Factor Structure	
	FACTOR ANALYTIC DESIGNS	526
	Alternative Designs / Three-Mode Factor Analysis	
	AD-LIB FACTORING	531
	HIGHER-ORDER FACTORS	532
	HOW TO FOOL YOURSELF WITH FACTOR ANALYSIS	533

AN OUTLOOK ON EXPLORATORY FACTOR ANALYSIS	535
Practical Considerations in Factor Analysis	
SUMMARY	536
SUGGESTED ADDITIONAL READINGS	541
13 Confirmatory Factor Analysis	542
CHAPTER OVERVIEW	542
SPEARMAN'S GENERAL FACTOR SOLUTION	544
COMPARING FACTORS IN DIFFERENT ANALYSES	548
Classical Approaches to Testing Factor Invariance / Some Practical Aspects of Comparing Factor Structures / Comparing Overall Solutions / ACS Approaches	
TESTING WEAK THEORIES (THEORIES CONCERNING GROUPINGS OF VARIABLES)	554
Multiple Group Confirmatory Analysis / Procrustes Confirmatory Analysis/ACS Confirmatory Analysis / A Comparison of the Three Approaches	
FACTORING CATEGORICAL VARIABLES (ITEM LEVEL FACTORING)	570
ACS and Related Approaches with PM Measures / Multiscale Analyses	
TESTING STRONG THEORIES	576
Introduction to the Full ACS Model / ACS Notation / Assumptions / Properties of Path Coefficients / A Note on Inferring Causality from Correlational Data / Model Specification in ACS / Recursive and Nonrecursive Models / Cross-lagged Correlation / Applying ACS / Reapplying ACS / Classical Approaches to Strong Theories	
SUMMARY	590
SUGGESTED ADDITIONAL READINGS	594
PART 5 ADDITIONAL STATISTICAL MODELS, CONCEPTS, AND ISSUES	595
14 Profile Analysis, Discriminant Analysis, and Multidimensional Scaling	597
CHAPTER OVERVIEW	597
CLUSTER ANALYSIS	598
PROBLEMS IN PROFILE ANALYSIS	599
Characteristics of Score Profiles	
CLUSTERING OF PROFILES	601
Measures of Profile Similarity / Distance Measure / Hierarchical and Overlapping Clustering	
RAW-SCORE FACTOR ANALYSIS	604
An Example of Raw-Score Factor Analysis / How Raw-Score Factor Analysis Works / Transformations of Variables / Transformations of Profiles	

DISCRIMINANT ANALYSIS	610
Geometric Interpretation of Discriminant Analysis / Linear Discriminant Function / Multiple Linear Discriminant Functions / Placement / Evaluation of Discriminant Analysis	
PATTERN ANALYSIS	620
Discovering Latent Groups / Discriminating among Existing Groups / Evaluation of Pattern Analysis	
MULTIDIMENSIONAL SCALING	621
Spatial Conceptions of MDS / An Overview of Alternative Approaches to MDS / Psychophysical Methods Based upon Similarity / Psychophysical Methods Based upon Attribute Ratings / Indirect Methods / Vector-Space Ratio Methods / Euclidian Distance Ratio Methods / Interval Methods / Ordinal Methods and ALSCAL / Some Empirical Properties of Alternative MDS Solutions / MDS of Correlation Matrices / Scaling of Individual Differences / An Example of the Use of MDS / Some Concluding Comments	
DOMINANCE (PREFERENCE) SCALING	645
The Unfolding Concept / Multidimensional Unfolding and ALSCAL	
SUMMARY	648
SUGGESTED ADDITIONAL READINGS	651
15 The Analysis of Categorical Data, Binary Classification, and Alternatives to Geometric Representations	652
CHAPTER OVERVIEW	652
CATEGORICAL MODELING	654
Two-way Independence / Association (Nonindependence) / Alternative Models for the 2 x 2 Case / Measures of Association in the 2 x 2 Design / More about C^2 / The Generalized Logit Variant / Structural and Random Zeros / Multiple Levels on a Variable / Higher-Order Designs / Predictor-Criterion Models / Multiple Response Categories in Predictor-Criterion Models/Some Important Assumptions / Log-linear Modeling and Item Response Theory / More-Specific Categorical Models / Logistic Regression / Comparing Groups with Logistic Regression / An Illustrative Problem / A Note on Residuals / Predicting Categorical Criteria	
BINARY CLASSIFICATION	680
Classical Signal Detection / Categorical Modeling Approaches to the Equal Variance Gaussian Model / General Recognition Theory / Application to Condensation Tasks / MDS, Dissimilarity Judgments, and General Recognition Theory / Implications for Measurement	
NONGEOMETRIC AND NON-EUCLIDIAN MODELS	696
Nearest Neighbors / Tree Representations / Network and Graph Theoretic Approaches / Conclusions	

SUMMARY	704
SUGGESTED ADDITIONAL READINGS	708
REFERENCES	709
INDEXES	
Name Index	735
Subject Index	741