

CONTENTS

PREFACE XI

ABOUT THE AUTHOR XIII

CHAPTER 1 Research Strategies and the Control of Nuisance Variables I

- 1.1 Introduction 1
- 1.2 Formulation of Plans for the Collection and Analysis of Data 2
- 1.3 Research Strategies 6
- 1.4 Other Research Strategies 9
- 1.5 Threats to Valid Inference Making 16
- 1.6 Other Threats to Valid Inference Making 19
- 1.7 Controlling Nuisance Variables and Minimizing Threats to Valid Inference Making 21
- 1.8 Ethical Treatment of Subjects 24
- 1.9 Review Exercises 26

CHAPTER 2 Experimental Designs: An Overview 30

- 2.1 Introduction 30
- 2.2 Overview of Some Basic Experimental Designs 30
- 2.3 Classification of Analysis of Variance Designs 45
- 2.4 Selecting an Appropriate Design 48
- 2.5 Review of Statistical Inference 49
- 2.6 Review Exercises 70

CHAPTER 3 Fundamental Assumptions in Analysis of Variance 77

- 3.1 Sampling Distributions in Analysis of Variance 77
- 3.2 Partition of the Total Sum of Squares 86
- 3.3 Expectation of the Mean Squares 92
- 3.4 The F Statistic in Analysis of Variance 95

- 3.5 Effects of Failure to Meet Assumptions in Analysis of Variance 96
- 3.6 Transformations 103
- 3.7 Other Procedures for Dealing With Nonnormality, Unequal Variances, and Outliers 108
- 3.8 Supplement for Section 3.3 111
- 3.9 Review Exercises 117

CHAPTER 4 Completely Randomized Design 125

- 4.1 Description of the Design 125
- 4.2 Exploratory Data Analysis 127
- 4.3 Computational Example for CR-4 Design 131
- 4.4 Measures of Strength of Association and Effect Size 134
- 4.5 Power and the Determination of Sample Size 138
- 4.6 Random-Effects Model 145
- 4.7 Advantages and Disadvantages of CR- p Design 146
- 4.8 Review Exercises 146

CHAPTER 5 Multiple Comparison Tests 154

- 5.1 Introduction to Multiple Comparison Tests 154
- 5.2 Procedures for Testing $p - 1$ a Priori Orthogonal Contrasts 170
- 5.3 Procedures for Testing $p - 1$ Contrasts Involving a Control Group Mean 176
- 5.4 Procedures for Testing C a Priori Nonorthogonal Contrasts 179
- 5.5 Procedures for Testing All Pairwise Contrasts 187
- 5.6 Testing All Contrasts Suggested by an Inspection of the Data 198
- 5.7 Other Multiple Comparison Procedures 200
- 5.8 Comparison of Multiple Comparison Procedures 201
- 5.9 Review Exercises 201

CHAPTER 6 Trend Analysis 209

- 6.1 Introduction to Tests for Trends 209
- 6.2 Test for the Linear Trend Contrast 211
- 6.3 Tests for Higher-Order Trend Contrasts 218
- 6.4 Linear and Curvilinear Correlation 225
- 6.5 Variance Accounted for by Mean Contrasts 225
- 6.6 Review Exercises 227

CHAPTER 7 General Linear Model Approach to ANOVA 233

- 7.1 Comparison of Analysis of Variance and Multiple Regression 233
- 7.2 Operations With Vectors and Matrices 234
- 7.3 General Linear Model 244

- 7.4 Estimating the Parameters in a Regression Model 247
- 7.5 Regression Model Approach to ANOVA 253
- 7.6 Alternative Conception of the Test of $\beta_1 = \beta_2 = \cdots = \beta_{h-1} = 0$ 262
- 7.7 Cell Means Model Approach to ANOVA 266
- 7.8 Summary 272
- 7.9 Review Exercises 272

CHAPTER 8 Randomized Block Designs 280

- 8.1 Description of Randomized Block Design 280
- 8.2 Computational Example for RB- p Design 288
- 8.3 Alternative Models for RB- p Design 296
- 8.4 Some Assumptions Underlying RB- p Design 303
- 8.5 Procedures for Testing Differences Among Means 314
- 8.6 Tests for Trends 319
- 8.7 Relative Efficiency of Randomized Block Design 321
- 8.8 Cell Mean Model Approach to the RB- p Design 322
- 8.9 Generalized Randomized Block Design 336
- 8.10 Advantages and Disadvantages of RB- p and GRB- p Designs 343
- 8.11 Review Exercises 344

CHAPTER 9 Completely Randomized Factorial Design With Two Treatments 357

- 9.1 Introduction to Factorial Designs 357
- 9.2 Description of Completely Randomized Factorial Design 357
- 9.3 Computational Example for CRF- pq Design 360
- 9.4 Experimental Design Model for CRF- pq Design 368
- 9.5 Procedures for Testing Differences Among Means 372
- 9.6 More on the Interpretation of Interactions 373
- 9.7 Tests for Trends 386
- 9.8 Estimating Strength of Association, Effect Size, Power, and Sample Size 395
- 9.9 Rules for Deriving Expected Values of Mean Squares 400
- 9.10 Quasi F Statistics 404
- 9.11 Preliminary Tests on the Model and Pooling Procedures 406
- 9.12 Analysis of Completely Randomized Factorial Designs With $n = 1$ 409
- 9.13 Cell Means Model Approach to Completely Randomized Factorial Design 411
- 9.14 Analysis of Completely Randomized Factorial Designs With Missing Observations and Empty Cells 422
- 9.15 Advantages and Disadvantages of Factorial Designs 431
- 9.16 Review Exercises 432

CHAPTER 10 **Completely Randomized Factorial Design
With Three or More Treatments and
Randomized Block Factorial Design** **439**

- 10.1 Introduction to CRF- pqr Design 439
- 10.2 Computational Example for CRF- pqr Design 441
- 10.3 Patterns Underlying Sum-of-Squares Formulas 448
- 10.4 Formulating Coefficient Matrices for the Cell Means Model 451
- 10.5 Introduction to Randomized Block Factorial Design 458
- 10.6 Computational Example for RBF- pq Design 460
- 10.7 Expected Value of Mean Squares and the Sphericity Conditions 465
- 10.8 Cell Means Model Approach to Randomized Block Factorial Design 469
- 10.9 Minimizing Time and Location Effects by Using a Randomized Block Factorial Design 484
- 10.10 Review Exercises 485

CHAPTER 11 **Hierarchical Designs** **489**

- 11.1 Introduction to Hierarchical Designs 489
- 11.2 Computational Example for CRH- $pq(A)$ Design 492
- 11.3 Experimental Design Model for CRH- $pq(A)$ Design 496
- 11.4 Procedures for Testing Differences Among Means 498
- 11.5 Estimating Strength of Association, Effect Size, Power, and Sample Size 500
- 11.6 Description of Other Completely Randomized Hierarchical Designs 502
- 11.7 Cell Means Model for Completely Randomized Hierarchical Design 515
- 11.8 Cell Means Model for Randomized Block Hierarchical Design 521
- 11.9 Advantages and Disadvantages of Hierarchical Designs 530
- 11.10 Review Exercises 531

CHAPTER 12 **Split-Plot Factorial Design:
Design With Group-Treatment Confounding** **541**

- 12.1 Description of Split-Plot Factorial Design 541
- 12.2 Computational Example for SPF- $p \cdot q$ Design 544
- 12.3 Experimental Design Model for SPF- $p \cdot q$ Design 550
- 12.4 Some Assumptions Underlying SPF- $p \cdot q$ Design 555
- 12.5 Procedures for Testing Differences Among Means 560
- 12.6 Procedures for Testing Hypotheses About Simple Main Effects and Treatment-Contrast Interactions 566
- 12.7 Relative Efficiency of Split-Plot Factorial Design 569
- 12.8 Computational Procedures for SPF- $pr \cdot q$ Design 570
- 12.9 Computational Procedures for SPF- $p \cdot rt \cdot q$ Design 579
- 12.10 Computational Procedures for SPF- $p \cdot qr$ Design 583
- 12.11 Computational Procedures for SPF- $p \cdot qrt$ Design 590
- 12.12 Computational Procedures for SPF- $pr \cdot qt$ Design 595

- 12.13 Evaluation of Sequence Effects 595
- 12.14 Cell Means Model Approach to SPF- p - q Design 597
- 12.15 Advantages and Disadvantages of Split-Plot Factorial Designs 613
- 12.16 Review Exercises 613

CHAPTER 13 Analysis of Covariance 621

- 13.1 Introduction to Analysis of Covariance 621
- 13.2 Rationale Underlying Covariate Adjustment 625
- 13.3 Layout and Computational Procedures for CRAC- p Design 633
- 13.4 Some Assumptions Underlying CRAC- p Design 637
- 13.5 Procedures for Testing Differences Among Means in CRAC- p Design 640
- 13.6 Analysis With Two Covariates 642
- 13.7 Analysis of Covariance for Randomized Block Design 646
- 13.8 Analysis of Covariance for Factorial Designs 648
- 13.9 Covariance Versus Stratification 654
- 13.10 Regression Model Approach to Analysis of Covariance 656
- 13.11 Cell Means Model Approach to Analysis of Covariance 660
- 13.12 Advantages and Disadvantages of Analysis of Covariance 663
- 13.13 Review Exercises 664

CHAPTER 14 Latin Square and Related Designs 671

- 14.1 Description of Latin Square Design 671
- 14.2 Construction and Randomization of Latin Squares 672
- 14.3 Computational Example for Latin Square Design 675
- 14.4 Computational Procedures for $n = 1$ 681
- 14.5 Experimental Design Model for Latin Square Design 684
- 14.6 Procedures for Testing Differences Among Means 687
- 14.7 Relative Efficiency of Latin Square Design With $n = 1$ 687
- 14.8 Analysis of Covariance for Latin Square Design 690
- 14.9 Cell Means Model Approach to Latin Square Design 692
- 14.10 Graeco-Latin Square Design 700
- 14.11 Hyper-Graeco-Latin Square Designs 702
- 14.12 Crossover Design 703
- 14.13 Advantages and Disadvantages of Designs Based on a Latin Square 710
- 14.14 Review Exercises 711

CHAPTER 15 Confounded Factorial Designs: Designs With Group-Interaction Confounding 719

- 15.1 Group-Interaction Confounding 719
- 15.2 Use of Modular Arithmetic in Constructing Confounded Designs 722
- 15.3 Computational Procedures for RBCF- 2^2 Design 726

- 15.4 Experimental Design Model for RBCF-2² Design 729
- 15.5 Layout and Analysis for RBCF-2³ Design 732
- 15.6 Complete Versus Partial Confounding 739
- 15.7 Computational Procedures for RBPF-2³ Design 740
- 15.8 Computational Procedures for RBCF-3² and RBPF-3² Designs 749
- 15.9 Analysis Procedures for Higher-Order Confounded Designs 760
- 15.10 Alternative Notation and Computational Systems 772
- 15.11 Computational Procedures for RBPF-3² Design 775
- 15.12 Cell Means Model Approach to RBCF- p^k Design 785
- 15.13 Group-Interaction Confounding by Means of a Latin Square 787
- 15.14 Advantages and Disadvantages of Confounding in Factorial Designs 793
- 15.15 Review Exercises 796

CHAPTER 16 Fractional Factorial Designs: Designs With Treatment-Interaction Confounding 803

- 16.1 Introduction to Fractional Factorial Designs 803
- 16.2 General Procedures for Constructing Completely Randomized Fractional Factorial Designs 805
- 16.3 Computational Procedures for CRFF-2⁴⁻¹ Design 810
- 16.4 Computational Procedures for CRFF-3⁴⁻¹ Design 814
- 16.5 Cell Means Model for CRFF- p^{k-i} Design 820
- 16.6 General Procedures for Constructing RBFF- p^{k-i} Designs 823
- 16.7 Other Types of CRFF and RBFF Designs 824
- 16.8 Introduction to Latin Square Fractional Factorial Designs 825
- 16.9 Computational Procedures for LSFF- p^2 Design 828
- 16.10 Computational Procedures for LSFF- p^3t Design 832
- 16.11 Computational Procedures for LSFF- p^4u Design 838
- 16.12 Computational Procedures for GLSFF- p^3 Design 840
- 16.13 Advantages and Disadvantages of Fractional Factorial Designs 841
- 16.14 Review Exercises 842

- APPENDIX A **Rules of Summation 847**
- APPENDIX B **Rules of Expectation, Variance, and Covariance 852**
- APPENDIX C **Orthogonal Coefficients for Unequal Intervals and Unequal n_s 858**
- APPENDIX D **Matrix Algebra 863**
- APPENDIX E **Tables 891**
- APPENDIX F **Answers to Starred Exercises 952**
- REFERENCES **1035**
- INDEX **1048**