Contents

Preface xi

CHAPTER 1 INTRODUCTION 1

1.1 Variability and the Need for Statistics 1
1.2 Systematic Versus Random Variability 3
1.3 Error Variance Again 5
1.4 Reducing Error Variance 5
1.5 Overview of the Book 7
1.6 Concluding Remarks 7

CHAPTER 2 LOOKING AT DATA: UNIVARIATE DISTRIBUTIONS 10

2.1 Introduction 10
2.2 Exploring a Single Sample 11
2.3 Comparing Two Data Sets 18
2.4 Other Measures of Location and Spread: The Mean and Standard Deviation 20
2.5 Standardized (z) Scores 27
2.6 Measures of the Shape of a Distribution 28
2.7 Concluding Remarks 33

CHAPTER 3 LOOKING AT DATA: RELATIONS BETWEEN QUANTITATIVE VARIABLES 37

3.1 Introduction 37
3.2 Some Examples 37
3.3 Linear Relations 43
3.4 The Pearson Product-Moment Correlation Coefficient 44

3.5 Linear Regression 51
3.6 The Coefficient of Determination, r^2 54
3.7 Influential Data Points and Resistant Measures of Regression 55
3.8 Describing Nonlinear Relations 56
3.9 Concluding Remarks 56

CHAPTER 4 PROBABILITY AND THE BINOMIAL DISTRIBUTION 61

4.1 Introduction 61
4.2 Discrete Random Variables 62
4.3 Probability Distributions 63
4.4 Some Elementary Probability 67
4.5 The Binomial Distribution 75
4.6 Means and Variances of Discrete Distributions 79
4.7 Hypothesis Testing 80
4.8 Independence and the Sign Test 86
4.9 More About Assumptions and Statistical Tests 89
4.10 Concluding Remarks 89

CHAPTER 5 ESTIMATION AND HYPOTHESIS TESTS: THE NORMAL DISTRIBUTION 100

5.1 Introduction 100
5.2 Continuous Random Variables 100
5.3 The Normal Distribution 102
5.4 Point Estimates of Population Parameters 104
5.5 Inferences About Population Means: The One-Sample Case 112
5.6 Inferences About Population Means: The Correlated-Samples Case 117
5.7 The Power of the *z* Test 119
5.8 Hypothesis Tests and CIs 122
5.9 Validity of Assumptions 123
5.10 Comparing Means of Two Independent Populations 125
5.11 The Normal Approximation to the Binomial Distribution 128
5.12 Concluding Remarks 129

CHAPTER 6 ESTIMATION, HYPOTHESIS TESTS, AND EFFECT SIZE: THE *t* DISTRIBUTION 140

6.1 Introduction 140
6.2 Inferences About a Population Mean 141
6.3 The Standardized Effect Size 145
6.4 Power of the One-Sample *t* Test 147
6.5 The *t* Distribution: Two Independent Groups 152
6.6 Standardized Effect Size for Two Independent Means 156
6.7 Power of the Test of Two Independent Means 157
6.8 Assumptions Underlying the Two-Group *t* Test 158
6.9 Contrasts Involving More than Two Means 161
6.10 Correlated Scores or Independent Groups? 165
6.11 Concluding Remarks 167

CHAPTER 7 THE CHI-SQUARE AND *F* DISTRIBUTIONS 173

7.1 Introduction 173
7.2 The χ^2 Distribution 174
7.3 Inferences About the Population Variance 175
7.4 The *F* Distribution 179
7.5 Inferences About Population Variance Ratios 182
7.6 Relations Among Distributions 185
7.7 Concluding Remarks 186

CHAPTER 8 BETWEEN-SUBJECTS DESIGNS: ONE FACTOR 191

8.1 Introduction 191
8.2 Exploring the Data 193
8.3 The Analysis of Variance 195
8.4 The Model for the One-Factor Design 201
8.5 Assessing the Importance of the Independent Variable 207
8.6 Power of the *F* Test 212
8.7 Assumptions Underlying the *F* Test 216
8.8 Concluding Remarks 227

CHAPTER 9 CONTRASTS AMONG MEANS 233

9.1 Introduction 233
9.2 Definitions and Examples of Contrasts 234
9.3 Calculations of the *t* Statistic for Testing Hypotheses About Contrasts 235
9.4 The Proper Unit for the Control of Type 1 Error 241
9.5 Planned Versus Post Hoc Contrasts 243
9.6 Controlling the FWE for Families of *K* Planned Contrasts 244
9.7 Testing All Pairwise Contrasts 247
9.8 Comparing $a - 1$ Treatment Means with a Control: Dunnett's Test 255
9.9 Controlling the Familywise Error Rate for Post Hoc Contrasts 256
9.10 The Sum of Squares Associated with a Contrast 258
9.11 Concluding Remarks 260

CHAPTER 10 TREND ANALYSIS 267

10.1 Introduction 267
10.2 Linear Trend 268
10.3 Testing Nonlinear Trends 274
10.4 Concluding Remarks 280

CHAPTER 11 MULTIFACTOR BETWEEN-SUBJECTS DESIGNS: SIGNIFICANCE TESTS IN THE TWO-WAY CASE 284

11.1 Introduction 284
11.2 A First Look at the Data 285
11.3 Two-Factor Designs: The ANOVA 288
11.4 The Structural Model and Expected Mean Squares 295
11.5 Main Effect Contrasts 297

11.6 More About Interaction 298
11.7 Simple Effects 302
11.8 Two-Factor Designs: Trend Analysis 305
11.9 Concluding Remarks 309

CHAPTER 12 MULTIFACTOR BETWEEN-SUBJECTS DESIGNS: FURTHER DEVELOPMENTS 315

12.1 Introduction 315
12.2 Measures of Effect Size 315
12.3 Power of the *F* Test 318
12.4 Unequal Cell Frequencies 319
12.5 Three-Factor Designs 324
12.6 More than Three Independent Variables 332
12.7 Pooling in Factorial Designs 332
12.8 Blocking to Reduce Error Variance 335
12.9 Concluding Remarks 336

CHAPTER 13 REPEATED-MEASURES DESIGNS 342

13.1 Introduction 342
13.2 The Additive Model and Expected Mean Squares for the $S \times A$ Design 345
13.3 The Nonadditive Model for the $S \times A$ Design 352
13.4 Hypothesis Tests Assuming Nonadditivity 355
13.5 Power of the *F* Test 363
13.6 Multifactor Repeated-Measures Designs 363
13.7 Fixed or Random Effects? 371
13.8 Nonparametric Procedures for Repeated-Measures Designs 372
13.9 Concluding Remarks 377

CHAPTER 14 MIXED DESIGNS: BETWEEN-SUBJECTS AND WITHIN-SUBJECTS FACTORS 386

14.1 Introduction 386
14.2 One Between-Subjects and One Within-Subjects Factor 386
14.3 Rules for Generating Expected Mean Squares 392
14.4 Measures of Effect Size 394
14.5 Power Calculations 396
14.6 Contrasting Means in Mixed Designs 397
14.7 Testing Simple Effects 401
14.8 Pretest–Posttest Designs 402
14.9 Additional Mixed Designs 403
14.10 Concluding Remarks 407

CHAPTER 15 USING CONCOMITANT VARIABLES TO INCREASE POWER: BLOCKING AND ANALYSIS OF COVARIANCE 412

15.1 Introduction 412
15.2 Example of an ANCOVA 415

15.3 Assumptions and Interpretation in an ANCOVA 422
15.4 Testing Homogeneity of Slopes 427
15.5 More About ANCOVA Versus Treatments × Blocks 428
15.6 Estimating Power in an ANCOVA 430
15.7 ANCOVA in Higher-Order Designs 431
15.8 Some Extensions of the ANCOVA 431
15.9 Concluding Remarks 432

CHAPTER 16 HIERARCHICAL DESIGNS 436

16.1 Introduction 436
16.2 Groups Within Treatments 437
16.3 Groups Versus Individuals 443
16.4 Extensions of the Groups-Within-Treatments Design 445
16.5 Items Within Treatments 449
16.6 Concluding Remarks 452

CHAPTER 17 LATIN SQUARES AND RELATED DESIGNS 457

17.1 Introduction 457
17.2 Selecting a Latin Square 459
17.3 The Single Latin Square 461
17.4 The Replicated Latin Square Design 469
17.5 Balancing Carry-Over Effects 474
17.6 Greco-Latin Squares 476
17.7 Concluding Remarks 477

CHAPTER 18 MORE ABOUT CORRELATION 480

18.1 Introduction 480
18.2 Further Issues in Understanding the Correlation Coefficient 481
18.3 Inference About Correlation 489
18.4 Partial Correlations 501
18.5 Other Measures of Correlation 504
18.6 Concluding Remarks 511

CHAPTER 19 MORE ABOUT BIVARIATE REGRESSION 519

19.1 Introduction 519
19.2 Regression Toward the Mean 520
19.3 Inference in Linear Regression 522
19.4 An Example: Regressing Cholesterol Level on Age 532
19.5 Checking for Violations of Assumptions 534
19.6 Locating Outliers and Influential Data Points 542
19.7 Testing Independent Slopes for Equality 548
19.8 Repeated-Measures Designs 549
19.9 Multilevel Modeling 551
19.10 Concluding Remarks 551

CHAPTER 20 MULTIPLE REGRESSION 562

20.1 Introduction 562
20.2 A Regression Example with Several Predictor Variables 563
20.3 The Nature of the Regression Coefficients 572
20.4 The Multiple Correlation Coefficient and the Partitioning of Variability in Multiple Regression 573
20.5 Inference in Multiple Regression 580
20.6 Selecting the Best Regression Equation for Prediction 591
20.7 Explanation Versus Prediction in Regression 593
20.8 Testing for Curvilinearity in Regression 598
20.9 Including Interaction Terms in Multiple Regression 601
20.10 Multiple Regression in Repeated-Measures Designs 607
20.11 Concluding Remarks 608

CHAPTER 21 REGRESSION WITH CATEGORICAL AND QUANTITATIVE VARIABLES: THE GENERAL LINEAR MODEL 614

21.1 Introduction 614
21.2 One-Factor Designs 615
21.3 Regression Analyses and Factorial Designs 621
21.4 Using Categorical and Continuous Variables in the Same Analysis 630
21.5 Coding Designs with Within-Subjects Factors 634
21.6 Concluding Remarks 637

APPENDIXES

Appendix A Notation and Summation Operations 641
Appendix B Expected Values and Their Applications 649
Appendix C Statistical Tables 653

Answers to Selected Exercises 685

Endnotes 721

References 729

Author Index 743

Subject Index 749