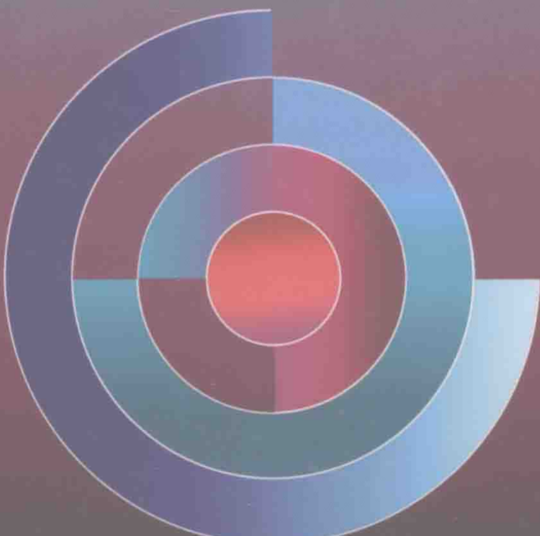
Fourth Edition

Statistics in Kinesiology



William J. Vincent | Joseph P. Weir

FOURTH EDITION

Statistics in Kinesiology

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This book is dedicated to my eternal family:
Clarence, Orpha, Jerry, Diana, Steven,
Daniel, Susan, Gail, David, Nancy,
and all who have gone before or will come after.

—William J. Vincent, EdD

To Sumiko Inoue Weir (1933-1982)
and Julian Paul Weir (1923-2009).

—Joseph P. Weir, PhD

Preface

This edition of *Statistics in Kinesiology* represents a second phase in the life of this unique book. The most obvious change is the addition of Joe Weir of Des Moines University Osteopathic Medical Center as a coauthor. Bill Vincent brought to the first three editions of this book more than 35 years of experience in teaching statistics. Joe Weir has more than 15 years of experience in teaching research and statistics, primarily to physical therapy students. We both emphasize the practical use of statistics as a tool to help those in the movement sciences (e.g., physical educators, coaches, biomechanists, sport psychologists, exercise physiologists, athletic trainers, and physical therapists) analyze quantitative data. The goal is always to educate students in the proper use of statistical tools that can help them answer questions in their specific disciplines.

In updating this book, we retained all the qualities that made previous editions such a success. Specifically, the examples of statistical procedures still focus on variables in kinesiology so that students can better relate to how the procedures are used and how the procedures can help them answer questions. We retained the use of hand calculations because we think that doing some of the calculations manually on simple data is an important learning tool. Nonetheless, the mathematics shown in the examples involve only basic algebra skills. As with the previous editions, we emphasize topics that are commonly seen in our disciplines, such as repeated measures analysis of variance and the interpretation of interactions in factorial analyses of variance.

We have also made some substantial changes to the content of the book. Some topics have been expanded. For example, we increased coverage of effect sizes and the use of confidence intervals. We now have a separate chapter on analysis of covariance because it is becoming the technique of choice for analyzing the pretest–posttest control group design. Similarly, we expanded the coverage of the quantification of reliability. We also added new content on clinical measures of association, such as relative risk and odds ratios, that are relevant to clinical disciplines in kinesiology.

We hope this fourth edition will be a valuable tool in helping both students and researchers analyze quantitative data in the kinesiological disciplines.

—William J. Vincent , EdD
—Joseph P. Weir, PhD

Acknowledgments

My deepest acknowledgments are to my students who over the years have inspired me and encouraged me to write this book and its subsequent editions. They are the ones who have challenged me and provided the motivation to teach and to write. While administrative responsibilities are rewarding, I must honestly say that the classroom is where I find the greatest joy. It is there that the interaction takes place which inspires teachers and empowers learners.

I would like to acknowledge four people who have had a major impact on my professional life: Dr. Glen Arnett (deceased), who hired me in my first job at California State University, Northridge, Dr. Ruel Barker, Chair, and Dr. Robert Conlee, Dean at Brigham Young University, who hired me as an adjunct professor after retirement from CSUN, and Dr. Larry Hall who continued to support me for many years at BYU.

Special thanks to Kevin Matz and his staff at Human Kinetics for guiding us through this fourth edition with expertise and skill. And to my friend and coauthor, Dr. Joe Weir: thanks Joe for the great contributions you have made to this edition.

Finally I acknowledge my wife Diana, who for 53 years has been my eternal sweetheart and the love of my life. She has supported me all the way.

—William J. Vincent EdD

I am indebted to many people who have impacted me both professionally and personally over the years. In particular, I would like to thank Dr. Terry Housh at the University of Nebraska-Lincoln, who was my PhD advisor and remains my friend and mentor, and Dr. Ronald DeMeersman, who shepherded me into the professoriate at Teachers College, Columbia University when I was fresh out of graduate school. In addition, it has been a great pleasure to collaborate with Dr. Bill Vincent on the fourth edition of this book. He is a gentleman of the highest order. Finally, I wish to thank my wife, Dr. Loree Weir, who has been extremely supportive of all my professional pursuits.

—Joseph P. Weir, PhD

List of Key Symbols

α	1. Greek letter, lowercase *alpha* 2. Area for rejection of H_0 on a normal curve
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
β	Slope of a line; Greek letter, lowercase *beta*
B	Greek letter, uppercase *beta*
χ	Greek letter, lowercase *chi*
χ^2	*Chi*-square
C	1. Column 2. Number of comparisons 3. Constant 4. Cumulative frequency 5. *Y*-intercept of a line
d	Deviation (the difference between a raw score and a mean)
df	Degrees of freedom
D_1	The 10th percentile
E	Expected frequency
ES	Effect size
f	Frequency
F	Symbol for ANOVA
FW_α	Familywise *alpha*
H	The highest score in a data sheet. Also, the value of Kruskal-Wallis ANOVA for ranked data.
H_0	The null hypothesis
H_1	The research hypothesis
HSD	Tukey's honestly significant difference
i	Interval size in a grouped frequency distribution
I	Scheffé's confidence interval
IQR	Interquartile range
k	Number of groups in a data set
L	The lowest score in a data sheet
MANOVA	Multiple analysis of variance
M_G	The grand mean in ANOVA
MS	Mean square
MS_E	Mean square error
μ	1. Greek letter, lowercase *mu* 2. Mean of a population

n	Number of scores in a subgroup of the data set
N	Total number of scores in a data set
O	Observed frequency
ω	Greek letter, lowercase *omega*
ω^2	*Omega* squared
p	1. Probability of error 2. Proportion
P	Percentile
Q_1	The 25th percentile
r	Pearson's correlation coefficient
R	1. Range 2. Rows 3. Multiple correlation coefficient
R_1	Intraclass correlation
R_2	Coefficient alpha in intraclass correlation
ρ	1. Greek letter, lowercase *rho* 2. Spearman's rank order correlation coefficient
SD	Standard deviation (based on a sample)
SE_D	Standard error of the difference
SE_E	Standard error of the estimate
SE_M	Standard error of the mean
σ	1. Greek letter, lowercase *sigma* 2. Standard deviation (based on a population)
σ_p	Standard error of a proportion
SS	Sum of squares
Stanine	Standard score with middle score = 5 and $R = 1$ to 9
Σ	1. Greek letter, upper case *sigma* 2. The sum of a set of data
t	Student's t
T	T score (standard score with $\bar{X} = 50$ and $\sigma = 10.0$)
U	Mann-Whitney U test
V	Variance
X	A single raw score
$\bar{X}$	The mean
X_{mid}	The middle score in an interval of scores
Z	Z score (standard score with $\bar{X} = 0$ and $\sigma = 1.0$)
Z_α	Alpha point

Contents

CHAPTER 1

Measurement, Statistics, and Research

The most important step in the process of every science is the measurement of quantities . . . . The whole system of civilized life may be fitly symbolized by a foot rule, a set of weights, and a clock.

James Maxwell

Kinesiology is the study of the art and science of human movement. Artistic researchers may study and evaluate the qualitative beauty and form of human movement in dancers, gymnasts, or other artistic movement forms. Scientific researchers are interested in the quantitative characteristics of the human body as it moves. This book addresses the science of human movement and how it is measured, statistically analyzed, and evaluated.

Statistical procedures are the same regardless of the discipline from which the data was collected. The researcher chooses the proper procedure with which to analyze the data in a particular field. In this fourth edition of *Statistics in Kinesiology*, the authors include examples of statistical procedures from a wide ranging list of disciplines in kinesiology including physical education and sports; motor learning; biomechanics; exercise physiology; sport psychology; health, leisure studies, and recreation; athletic training; and physical therapy. From these examples, the reader can choose the appropriate procedures and apply them to data collected in any related field.

All science is based on precise and consistent measurement. Whether or not you consider yourself to be an exercise scientist or a physical education teacher or a physical therapist, you can gain much by learning proper measurement techniques. Exercise scientists measure various attributes of human performance in laboratories, teachers measure students' performances in the field, and physical therapists measure patients' performance in the clinic.

Maxwell's observation indicates that most measurements are of quantitative values—distance, force, and time. However, counting the frequency of occurrence of events is also measurement. These same measurements apply to kinesiology, where we commonly measure *distance* (how tall people are, or how far they can jump), *force* (how much they weigh, or how much they can lift), *time* (how fast they can run, or how long they can run at a given pace on a treadmill), and *frequency* (how many strides it takes to run 100 meters, or how many times the heart beats in a minute). These measurements are sometimes referred to as *objective* because they are made with mechanical instruments, which require minimal judgment on the part of the investigator and reduce investigator bias to a minimum.

Other measurements are classified as qualitative (or subjective), because they require human judgment, and are used to determine the quality of a performance, such as a gymnastics routine or a golf swing, or other factors such as a patient's level of pain.

What Is Measurement?

Put simply, **measurement** is the process of comparing a value to a standard. For example, we compare our own weight (the force of gravity on our body) with the standard of a pound or a kilogram every time we step on a scale. When a physical education teacher tests students in the long jump, the process of measurement is being applied. The standard with which the jumps are compared is distance (meters). When the teacher uses an instrument (in this case, a tape measure) to determine that a student has jumped 5.2 meters, this bit of information is called data.

Data are the result of measurement. When individual bits of data are collected they are usually disorganized. After all of the desired data points are known, they can be organized by a process called statistics. **Statistics** is a mathematical technique by which data are organized, treated, and presented for interpretation and evaluation. **Evaluation** is the philosophical process of determining the worth of the data.

To be useful, the data from measurement must be reproducible—that is, a second measurement under the same conditions should produce the same result as the first measurement. Reproducibility is typically discussed under the heading of reliability. **Reliability** (sometimes referred to as the consistency of the data) is usually determined by the test–retest method, where the first measure is compared with a second or third measure on the same subjects under the same conditions. The quantification of reliability is addressed in chapter 13.

To be acceptable, data must also be valid. **Validity** refers to the soundness or the appropriateness of the test in measuring what it is designed to measure. Validity may be determined by a logical analysis of the measurement procedures or by comparison to another test known to be valid. In kinesiology, we often quantify validity by determining the extent to which a test is correlated to another index. The techniques of correlation and regression analysis are often used for these purposes. For example, the validity of skinfold measures for body fat assessment is quantified by how well the skinfold measures correlate with the results from underwater weighing. Chapters 8 and 9 address correlation and regression procedures that can be used to quantify validity.

Objectivity means that the data are collected without bias by the investigator. Bias can be detected by comparing an investigator's scores against those of an expert or panel of experts. Objectivity is sometimes referred to as inter-rater reliability (Morrow et al., 2000, p. 78).

Process of Measurement

Measurement involves four steps:

1. The object to be measured is identified and defined.
2. The standard with which the measured object will be compared is identified and defined.

3. The object is compared with the standard.
4. A quantitative statement is made of the relationship of the object to the standard.

For example, if we measured the height of a person who is 2 meters tall, we would conclude that the person's height (the object measured) is two times greater (the relationship) than 1 meter (the standard).

The standard used for comparison is critical to the measurement process. If the standard is not consistent, then the data will change each time an object is compared with that standard. In the English system of measurement, the original standard was not consistent. About 600 years ago in England the standard for measuring distance was the length of the king's foot. When the king died and another with a smaller or larger foot took his place, the standard changed and the length of all objects in the kingdom had to be redetermined.

The English system of measuring distance was originally based on anatomical standards such as foot, cubit (distance from the elbow to the finger tips—typically about 1.5 feet), yard (a typical stride for a person), and hand (the spread of the hand from end of the little finger to end of the thumb). Force was based on pounds (7,000 grains of wheat equaled 1 pound), and each pound was further divided into 16 ounces. In years when the rain was adequate the grains of wheat were large, but in drought years the grains were smaller. So the standard changed from year to year.

Eventually these measures were standardized, but the English system is difficult to use because it has no common numerical denominator for all units of measurement. Sixteen ounces make a pound, but 2,000 pounds make a ton; 2 cups make a pint and 2 pints make a quart, but it takes 4 quarts to make a gallon. Twelve inches make a foot, 3 feet make a yard, and 5,280 feet constitute a mile. It is no wonder that children have difficulty learning this system.

The metric system, which is more consistent and easier to understand, was first introduced in France in 1799. It is now used everywhere except in the United States and the countries in the British Empire. In this system, the units of measurement for distance, force, and volume are based on multiples of 10. The metric system uses the following terms:

Prefix	Value
milli	1/1,000
centi	1/100
zero	0
deca	10
hecto	100
kilo	1,000
mega	1,000,000
giga	1,000,000,000