chapter 1-1

The Scientific Method

Introduction

In order to solve problems and interpret data most investigators use what is commonly referred to as the “Scientific Method”. It involves several steps that when followed methodically result in meaningful interpretations and solutions. The process involves several basic steps:

Defining the Problem – Define the problem by observing the phenomenon and gaining an in depth knowledge of it.

Formulating the Hypothesis (Research Question) – The precise question being addressed by the study must be stated. Commonly called the Hypothesis, it helps define what type of research design will be required to answer the question.

Testing the Hypothesis – Design an experiment to test the hypothesis. When experimental data fits the hypothesis, the hypothesis supports a theory. A theory provides a set of predictions which explain the phenomena. Usually the theory will not fully explain the phenomenon so the scientist embarks upon a process of modification and retesting of the hypothesis until the best fit between real data and predictions is achieved.

Communicating the Findings – Having conducted a viable experiment, it is the responsibility of the researcher to communicate their findings to the rest of the scientific community and other relevant stakeholders, such as the public, policy makers, and health care professionals.

In this chapter the scientific method will be discussed. Later chapters will focus on specifics of data acquisition, research design and analysis methods.

Defining the Problem

The first step is to define the problem by observing the phenomenon and gaining an in depth knowledge of it. A researcher needs to have a strong educational background in the area of study, ensuring that they are familiar with pertinent research methods and have a good understanding of the phenomena being studied. Before embarking on the study it is very important to determine the exact status of recent research in this area. Has someone already

done this study? Is there a recent study with findings that would cause you to modify your research design? A thorough literature review of relevant research is essential to this process. Fortunately, there are many computer databases available that are readily searched by keyword, author name, etc. For example, Simon Fraser University has established a webpage specifically for Biomedical Physiology and Kinesiology listing links to many reference databases.

This webpage can be accessed at:

http://cufts2.lib.sfu.ca/CRDB/BVAS/browse/facets/subject/575

Table 1-1.1 A recent listing of available databases for Biomedical Physiology and Kinesiology related searches (accessed September 26, 2011).

Canadian Centre for Occupational Health and Safety Academic Support Program
Material safety databases maintained by the Canadian Centre for Occupational Health and Safety.

CINAHL with Full Text
CINAHL (Cumulative Index to Nursing and Allied Health Literature)is the authoritative resource for nursing and allied health professionals, students, educators and researchers.

EBM Reviews (search all at once)
Search all of OVID EBM Reviews at once.

Ergonomics Abstracts Online
Human factors in human-machine systems and physical environmental influences.

ERGONOMICSnetBASE
E-books in Ergonomics from CRC Press.

HCI (Human-Computer Interaction) Bibliography
Bibliography on the design, evaluation and implementation of interactive computing systems for human use.
Medline

MEDLINE®
(Medical Literature Analysis and Retrieval System Online) is the U.S. National Library of Medicine's® (NLM) premier bibliographic database that contains approximately 13 million references to journal articles in life sciences with a concentration on biomedicine.

Primal Pictures Interactive Anatomy
The most complete, detailed and accurate 3D model of human anatomy.

Sport Discus
Worldwide literature on exercise and sports.

Web of Science
A combined search of all of the Web of Science Citation indexes.

Medline (PubMed)
Use this version if you are an alumni or extramural borrower or external user accessing this database from home.

Literature searches can be time consuming and are often frustrating as you try to find the best combination of key words and search tactics. As with most things, literature searching becomes more efficient the more you do, as you learn the strategies that are most effective. However, the time and effort spent on a thorough literature search is invaluable, in first providing you with the information you require, but then by adding to the credibility of your published article.

Formulating The Hypothesis (Research Question)

Having mastered the pertinent literature the next step is to formulate the question that you would like to ask. In formal research terms this is referred to as formulating the Hypothesis. There are no guidelines on how to develop a hypothesis. A scientist's understanding, insight, creativity, hunches and even lucky guesses can all be part of the process of developing a hypothesis that will provide possible explanations for the phenomenon of interest.

In later chapters in this text, three major forms of questions or hypotheses commonly asked in Biomedical Physiology and Kinesiology are addressed: *Is There a Difference? Is there a Relationship? Can we predict?* Several statistics will be described that can be used to test such hypotheses. The appropriate statistic to use is determined by the specific research design and form of the data. For example, Chapter 2-9 deals with nonparametric tests appropriate for each of these types of questions. Nonparametric tests are used when a normal distribution cannot be assumed for the data.

You will probably be familiar with the term Null Hypothesis, whereby the statistical test determines the chance (or likelihood) of there being *no difference or relationship*, with the Alternate Hypothesis being that there is a difference or relationship. First you reject or fail to reject the Null Hypothesis. If you reject the Null Hypothesis, you accept the Alternate Hypothesis. Nowadays, it is more common to refer to the Research Hypothesis than the Alternate Hypothesis. What is it that you want to investigate with your study? Your research question might be; "Do elite squash players have more muscle in their racquet arm than in their non-racquet arm?". This question will be even more clearly defined in your hypothesis, including specific measurements, and the direction of the effect you expect. For example, "Skinfold-adjusted arm girth in elite squash players is significanlty greater in racquet arms than non-racquet arms."

The terms hypothesis, model, prediction, theory and law are all in commonly used in Biomedical Physiology and Kinesiology. They have distinctly different meanings and it is appropriate to clarify them at this point.

Hypothesis: A statement explaining the phenomenon under consideration. It is based upon the understanding of the situation before any testing via experiment has occurred. If for instance the dishwasher does not work, you may formulate the hypothesis that the dishwasher does not work because there is a power cut. If you check and find that power is on, then you could propose another hypothesis that the dishwasher control mechanism has failed, which could subsequently be tested.

Model: Once a hypothesis has been shown to hold true under certain circumstances it is called a model. Meteorology leans heavily on models for weather prediction. During a recent hurricane season came the amusing scenario on the CNN weather coverage of predictions of where the hurricane would make landfall in Florida. With the hurricane still out in the Atlantic, CNN was making predictions based upon 12 different models. They had narrowed the landfall of the hurricane down to one of three locations; crossing halfway up the east coast of Florida; or crossing the south coast and traveling right up the centre of Florida, with the third route being so far to the west that it would make landfall in Texas. Each of the twelve models would have at some point in time been validated on experimental data. However, obviously the models had limited validity in that they gave such different predictions on the same scenario. An example from Biomedical Physiology and Kinesiology, is that there are numerous muscle models of varying complexity that each work adequately under certain situations (Caldwell 2004). No one model perfectly predicts muscle performance but each one works under certain conditions and elucidates some part of the phenomenon.

Prediction: The term prediction is used in conjunction with experiment designs where the outcome is currently unknown. You make a prediction based upon your hypothesis or model and then design an experiment to test it. The process is usually iterative in that predictions are made, the accuracy of predictions is evaluated and the hypothesis is modified and new testable hypotheses are developed, and so on until the hypothesis holds true in many conditions.

Theory or Law: In this situation the hypothesis has been tested and shown to hold in many experimental situations with varying conditions. Our example here is the laws of motion that we so readily rely on in biomechanical analysis. They are seen to be valid in many situations. Theories or laws, since they are based upon repeated consistent experimental evidence are tough to dismiss. It is only after researchers have consistently shown that a theory or law does not hold under certain conditions that they will start to challenge and refashion it.

Testing the Hypothesis

Once the specific hypothesis has been developed an experiment needs to be designed to test it. The most complex and often the most challenging part of the process is the research design. Given that you can collect valid data, the validity of the study hinges upon a strong research design. The specifics of the design will define which statistical analyses are appropriate. In later chapters, as specific statistics are described, the type of research design that they are appropriate for will be discussed. Occasionally there are options for analysis and the researcher must justify their choice. The correct choice will obviously impact upon the validity of interpretations of the results found. Indeed the focus of the research project may itself be the evaluation of different ways of analysing the same data. Needless to say, a lot is dependent upon the correct choice of design and statistical analysis.

When testing the hypothesis those factors that have an effect on the experiment are called variables. There are basically three types of variables:

Independent variable:	The variable that you change or manipulate.
Dependent variable:	The variable that is observed. This will change in response to the independent variable.
Controlled variable:	The variable that is constant, being held constant by either research design or statistical analysis.

The focus of much of this text will be describing and using statistics for testing hypotheses, and after working through the examples given you should be comfortable deciding which statistics to apply in any given situation.

Ethics: When dealing with human subjects, ethical guidelines on experimentation on humans must be followed. Every university has an ethics review process for human research. Minimally you would need to have an approved Informed Consent Form. This form is signed by the research subject after they have read it and have had all their questions satisfactorily answered. The contents of the form are critical. Information must be given on who you are; your motivation for the project; what exactly you are going to do; what is known about any possible risks of the measurements; what you are going to do with the data (i.e. assurance of subject anonymity, publish group data analysis in a journal article, present at a symposium or conference).

If you want to take photographs of subjects or use specific identifiable data for illustration, you would need to get written consent from the subject concerned.

There are strict rules on how you may solicit or interact with your subjects. At Simon Fraser University there is an Office of Research Ethics which administers the University Research Ethics Review Policies and Procedures in order to balance ethics and university research. These policies and procedures can be found at http://www.sfu.ca/policies/research/r20-01.htm

Communicating the Findings

Having tested your hypothesis by conducting an experiment, you must begin the process of communicating your finidings. This takes many forms. Scientists in a common field tend to keep in personal contact with each other and discuss findings often. When a study is finalised it is usual to write a research paper and publish it in the scientific literature. The most highly regarded and credible form of communication of your findings is in the form of a refereed journal article or paper.

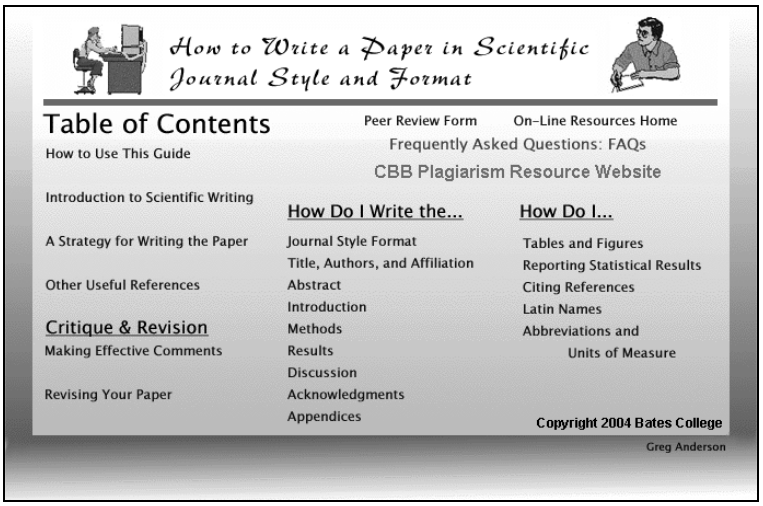

Figure 1-1.1: webpage by Greg Anderson of Bates College "How to Write a Paper in Scientific Journal Style and Format"

http://abacus.bates.edu/~ganderso/biology/resources/writing/HTWtoc.html

When faced with writing a research paper, the main questions that immediately come to mind are: What goes in the abstract, introduction, methods, results and discussion sections? The answer to these questions is beyond the scope of this text; however, for excellent information on how to write a refereed journal article. Dr. Greg. Anderson of Bates College (Lewiston, Maine, USA) has produced a comprehensive website giving guidance on all aspects of the process, it can be found at:

http://abacus.bates.edu/~ganderso/biology/resources/writing/HTWtoc.html

In order to achieve most wide-spread acceptance of your work, it is necessary to publish in a highly regarded refereed journal. A refereed journal is a publication dedicated to a specific area of study. You submit your paper to the journal where a senior editor or editorial board review the paper and send it out to two or three reviewers (or referees). These reviewers will be scientists with expertise in the area related to your paper. They will make written reports that are sent to the senior editor who will make a decision to reject your paper, accept without revisions, accept with minor revisions, or accept with major revisions. This will be communicated to you, and then you respond by making required changes (revisions) if appropriate, resubmit the paper, and hopefully the paper will then be accepted and published in the journal. This process can take over a year from submission of the manuscript to final publication.

Every journal requires that the paper you submit be in a standard format. Unfortunately all journals do not use the same format. Formats can vary in terms of headings required; number of words in the Abstract; referencing style etc. It is necessary to find out the format for the specific journal you wish to submit to. This can usually be found on the journal's website under a heading such as "Instructions to Authors" or "Author Guidelines." Table 1-1.2 lists website addresses for the "Instructions to Authors" web pages of journals commonly used by Biomedical Physiology and Kinesiology researchers.

Journal of Biomechanics	http://www.jbiomech.com/authorinfo
Journal of Neurophysiology	http://www.the-aps.org/publications/authorinfo/index.htm
Journal of Physiology	http://jp.physoc.org/site/misc/author.xhtml
Ergonomics	http://www.tandf.co.uk/journals/journal.asp?issn=0014-0139&linktype=44

Table 1-1.2: Website addresses for the "Instructions to Authors" web pages of journal commonly used by Biomedical Physiology and Kinesiology researchers.

An important point to note is that papers are not submitted looking like they do in the final journal. i.e. double columns with text and tables in line with text. Usually you are asked to submit papers double spaced with figures and tables on separate pages at the end of the document.

The style of referencing is the most common difference between different journal's submission requirements, such that if you change your mind about which journal to submit to, you will have to reformat your references.

American Journal of Clinical Nutrition	*Jennings G, Bluck L, Wright A, Elia M.* The use of infrared spectrophotometry for measuring body water spaces. Clin Chem **1999**;45:1077–81.
American Journal of Human Genetics	Devriendt K, Matthijs G, Legius E, Schollen E, Blockmans D, van Geet C, Degreef H, Cassiman J-J, Fryns J-P **(1997)** Skewed X-chromosome inactivation in female carriers of dyskeratosis congenita. Am J Hum Genet 60:581–587
American Journal of Human Biology	Madrigal L. **1994**. Twinning rates in admixed Costa Rican populations. Am J Hum Biol 6:215–218.

Table 1-1.3: Comparison of reference styles of different journals

Table 1-1.3 shows referencing styles from 3 different journals. The year of publication has been highlighted in red. Note how it appears in different locations within the reference. In two of the examples it follows the authors names, although in the second, the year needs to be in brackets. In the third example the year follows the name of the journal. This is just one twist in

the many different referencing styles. The moral of this, is make sure you know the exact referencing style of the Journal you are submitting to. Changing all your references from one form to another can be very painful and time consuming. However, help is at hand. There are software programs written specifically to manage references, for all your writing needs. Endnote is an example of one bibliographic reference management software (http://www.endnote.com/). Simon Fraser University library has recently adopted an on-line program called REFWORKS for just this purpose, freely available to students, faculty and staff with university computing IDs at: http://www.lib.sfu.ca/my-library/refworks

Another form of communication is the scientific symposium or conference. Scientists in a specific field of study gather at some designated site and present verbal reports and/or poster presentations of the findings of their studies. Although these meetings tend to occur in nice places to visit, they are not simply an excuse for a holiday, they provide a function in the scientific method. They can produce valuable discussions between scientists which would probably not happen if they restricted themselves to their home institutions and publication via journals.

The Value of the Scientific Method

The Scientific Method certainly advances our knowledge of phenomena, but it also helps to keep bias out of research. The scientific method requires that you publish your findings in peer reviewed journals in order for your research to be given credibility. As part of this publication process you are required to provide full details of your subjects, methods and analysis techniques. In other words, everything needed to replicate your study. You therefore do not need to trust the publishing scientist, because you could repeat their work and confirm the findings. Biases do get into research, but they tend to be detected in the research design, and are picked up in peer review, and therefore such studies tend not to get published in reputable journals.

Much research is only possible because of appropriate levels of grant funding. Reputable funding agencies use a peer review process of grant submissions; therefore they are judged based on their adherence to the Scientific Method. Poorly designed studies tend not to get funded. Therefore the granting of funding process tends to enhance the credibility of research. This is not the case necessarily when private funding is provided by corporate bodies.

The status of a researcher is often judged by the amount of research dollars that they have attracted, because it is so intimately linked to the credibility of their research. Indeed, the overall degree of grant funding obtained by the research faculty, is a very important factor in evaluating the status of a university department or school.

Further Reading

Caldwell GE. 2004 Muscle Modeling. In: Research Methods in Biomechanics. Human Kinetics. Chap 9. pp 183-210.

Berg KE & RW Latin. 2004. Research Methods in Health, Physical Education, Exercise Science, and Recreation. Lippincott, Williams & Wilkins. (2nd Ed.)

Relevant Websites

Scientific Method: From Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/Scientific_method

Introduction to the Scientific Method. Frank L. H. Wolfs, University of Rochester, Rochester, NY http://teacher.nsrl.rochester.edu/phy_labs/AppendixE/AppendixE.html

"How to Write a Paper in Scientific Journal Style and Format". Greg Anderson, Bates College, Lewiston, Maine http://abacus.bates.edu/~ganderso/biology/resources/writing/HTWtoc.html

Endnote bibliographic reference management software. http://www.endnote.com/

REFWORKS, on-line bibliographic reference management software, freely available to Simon Fraser University students, faculty and staff with university computing IDs at: http://www.lib.sfu.ca/my-library/refworks