Statistics and the Evaluation of Evidence for Forensic Scientists

Second Edition

Colin G.G. Aitken

School of Mathematics,
The University of Edinburgh, UK

Franco Taroni

Ecole des Sciences Criminelles and
Institut de Médecine Légale,
The University of Lausanne, Switzerland

John Wiley & Sons, Ltd

Statistics and the Evaluation of Evidence for Forensic Scientists

STATISTICS IN PRACTICE

Founding Editor

Statistics in Practice is an important international series of texts which provide detailed coverage of statistical concepts, methods and worked case studies in specific fields of investigation and study.

With sound motivation and many worked practical examples, the books show in down-to-earth terms how to select and use an appropriate range of statistical techniques in a particular practical field within each title's special topic area.

The books provide statistical support for professionals and research workers across a range of employment fields and research environments. Subject areas covered include medicine and pharmaceutics; industry, finance and commerce; public services; the earth and environmental sciences, and so on.

The books also provide support to students studying statistical courses applied to the above areas. The demand for graduates to be equipped for the work environment has led to such courses becoming increasingly prevalent at universities and colleges.

It is our aim to present judiciously chosen and well-written workbooks to meet everyday practical needs. Feedback of views from readers will be most valuable to monitor the success of this aim.

A complete list of titles in this series appears at the end of the volume.

Statistics and the Evaluation of Evidence for Forensic Scientists

Second Edition

Colin G.G. Aitken

School of Mathematics,
The University of Edinburgh, UK

Franco Taroni

Ecole des Sciences Criminelles and
Institut de Médecine Légale,
The University of Lausanne, Switzerland

John Wiley & Sons, Ltd

Telephone (+44) 1243 779777

Email (for orders and customer service enquiries): cs-books@wiley.co.uk
Visit our Home Page on www.wileyeurope.com or www.wiley.com

Other Wiley Editorial Offices

John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030, USA

Jossey-Bass, 989 Market Street, San Francisco, CA 94103-1741, USA

Wiley-VCH Verlag GmbH, Boschstr. 12, D-69469 Weinheim, Germany

John Wiley & Sons Australia Ltd, 33 Park Road, Milton, Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01, Jin Xing Distripark, Singapore 129809

John Wiley & Sons Canada Ltd, 22 Worcester Road, Etobicoke, Ontario, Canada M9W 1L1

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Library of Congress Cataloging in Publication Data

Aitken, C.G.G.
Statistics and the evaluation of evidence for forensic scientists / Colin G.G. Aitken, Franco Taroni. — 2nd ed.
p. cm. — (Statistics in practice)
Includes bibliographical references and index.
ISBN 0-470-84367-5 (alk. paper)
1. Forensic sciences—Statistical methods. 2. Forensic statistics. 3. Evidence, Expert. I. Taroni, Franco. II. Title. III. Statistics in practice (Chichester, England)

HV8073.A55 2004
363.23′01′5195—dc22

2004048016

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 0-470-84367-5

Typeset in 10/12pt Photina by Integra Software Services Pvt. Ltd, Pondicherry, India
Printed and bound in Great Britain by TJ International, Padstow, Cornwall
This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

To

Liz, David and Catherine
and
Anna and Wanda

Contents

List of Tables

List of Figures

Foreword

The statistical evaluation of evidence is part of the scientific method, here applied to forensic circumstances. Karl Pearson was both perceptive and correct when he said that 'the unity of all science consists alone in its method, not in its material'. Science is a way of understanding and influencing the world in which we live. In this view it is not correct to say that physics is a science, whereas history is not: rather that the scientific method has been much used in physics, whereas it is largely absent from history. Scientific method is essentially a tool and, like any tool, is more useful in some fields than in others. If this appreciation of science as a method is correct, one might enquire whether the method could profitably be applied to the law, but before we can answer this it is necessary to understand something of what the scientific method involves. Books have been written on the topic, and here we confine ourselves to the essential ingredients of the method.

Two ideas dominate the scientific approach, observation and reasoning. Observation may be passive, as with a study of the motions of the heavenly bodies or the collection of medical records. Often it is active, as when an experiment is performed in a laboratory, or a controlled clinical trial is employed. The next stage is to apply reasoning to the observed data, usually to think of a theory that will account for at least some of the features seen in the data. The theory can then be used to predict further observations which are then made and compared with prediction. It is this see-saw between evidence and theory that characterises the scientific method and which, if successful, leads to a theory that accords with the observational material. Classic examples are Newton's theory to explain the motions of the planets, and Darwin's development of the theory of evolution. It is important to notice that, contrary to what many people think, uncertainty is present throughout any scientific procedure. There will almost always be errors in the measurements, due to variation in the material or limitations of the apparatus. A theory is always uncertain, and that is why it has to be rigorously tested. Only late in the cycle of movement between hard fact and mental activity is a theory admitted as being true. Even then the 'truth' is, in the long run, not absolute, as can be seen in the replacement of

Newton by Einstein. It is important to recognise the key role that uncertainty plays in the scientific method.

If the above analysis is correct, it becomes natural to see connections between the scientific method and legal procedures. All the ingredients are there, although the terminology is different. In a court of law, the data consist of the evidence pertinent to the case, evidence obtained by the police and other bodies, and presented by counsels for the defence and prosecution. There are typically only two theories, that the defendant is guilty or is innocent. As the trial proceeds, the see-saw effect is exhibited as evidence accumulates. Lawyers use an adversarial system, not openly present in scientific practice, but similar to the peer reviews that are employed therein. The most striking similarity between legal and scientific practice lies in the uncertainty that pervades both and the near-certainty that hopefully emerges at the end, the jurors oscillating as the evidence is presented. Indeed, it is striking that the law lightly uses the same term 'probability', as does the scientist, for expressing the uncertainty, for example in the phrase 'the balance of probabilities'.

The case for using the scientific method in a court of law therefore looks promising because the ingredients, in a modified form, are already present. Indeed, the method has had limited use, often by people who did not realise that they were acting in the scientific spirit, but it is only in the second half of the twentieth century that the method has been widely and successfully adopted. The major advances have taken place where the evidence itself is of the form that a scientist would recognise as material for study. Examples are evidence in the form of laboratory measurements on fragments of glass or types of blood, and, more recently and dramatically, DNA data. This book tells the story of this intrusion of science into law and, more importantly, provides the necessary machinery that enables the transition to be effected.

It has been explained how uncertainty plays important roles in both scientific method and courtroom procedure. It is now recognised that the only tool for handling uncertainty is probability, so it is inevitable that probability is to be found on almost every page of this book and must have a role in the courtroom. There are two aspects to probability: firstly, the purely mathematical rules and their manipulation; secondly, the interpretation of probability, that is, the connection between the numbers and the reality. Fortunately for legal applications, the mathematics is mostly rather simple – essentially it is a matter of appreciating the language and the notation, together with the use of the main tool, Bayes' theorem. Lawyers will be familiar with the need for specialist terms, so-called jargon, and will hopefully be appreciative of the need for a little mathematical jargon. Interpretation of probability is a more delicate issue, and difficulties here are experienced both by forensic scientists and lawyers. One miscarriage of justice was influenced by a scientist's flawed use of probability; another by a lack of legal appreciation of Bayes' theorem. A great strength of this book lies in the clear recognition of the interpretative problem and the inclusion of many examples of court cases, for example in Chapter 7. My personal view is that these problems are reduced by proper use of the mathematical notation and language, and by insisting that every statement of uncertainty is in the form of your probability of something, given clearly-stated assumptions. Thus the probability of the blood match, given that the defendant is innocent. Language that departs from this format can often lead to confusion.

The first edition (1995) of this book gave an admirable account of the subject as it was almost a decade ago. The current edition is much larger, and the enlargement reflects both the success of forensic science, by including recent cases, and also the new methods that have been used. A problem that arises in a courtroom, affecting both lawyers, witnesses and jurors, is that several pieces of evidence have to be put together before a reasoned judgement can be reached; as when motive has to be considered along with material evidence. Probability is designed to effect such combinations but the accumulation of simple rules can produce complicated procedures. Methods of handling sets of evidence have been developed; for example, Bayes nets in Chapter 14 and multivariate methods in Chapter 11. There is a fascinating interplay here between the lawyer and the scientist where they can learn from each other and develop tools that significantly assist in the production of a better judicial system. Another indication of the progress that has been made in a decade is the doubling in the size of the bibliography. There can be no doubt that the appreciation of some evidence in a court of law has been greatly enhanced by the sound use of statistical ideas, and one can be confident that the next decade will see further developments, during which time this book will admirably serve those who have cause to use statistics in forensic science.

D.V. Lindley
January 2004

Preface to the First Edition

In 1977 a paper by Dennis Lindley was published in *Biometrika* with the simple title 'A problem in forensic science'. Using an example based on the refractive indices of glass fragments, Lindley described a method for the evaluation of evidence which combined the two requirements of the forensic scientist, those of comparison and significance, into one statistic with a satisfactorily intuitive interpretation. Not unnaturally the method attracted considerable interest amongst statisticians and forensic scientists interested in seeking good ways of quantifying their evidence. Since then, the methodology and underlying ideas have been developed and extended in theory and application into many areas. These ideas, often with diverse terminology, have been scattered throughout many journals in statistics and forensic science and, with the advent of DNA profiling, in genetics. It is one of the aims of this book to bring these scattered ideas together and, in so doing, to provide a coherent approach to the evaluation of evidence.

The evidence to be evaluated is of a particular kind, known as transfer evidence, or sometimes trace evidence. It is evidence which is transferred between the scene of a crime and a criminal. It takes the form of traces – traces of DNA, traces of blood, of glass, of fibres, of cat hairs and so on. It is amenable to statistical analyses because data are available to assist in the assessment of variability. Assessments of other kinds of evidence, for example, eyewitness evidence, is not discussed.

The approach described in this book is based on the determination of a so-called likelihood ratio. This is a ratio of two probabilities, the probability of the evidence under two competing hypotheses. These hypotheses may be that the defendant is guilty and that he is innocent. Other hypotheses may be more suitable in certain circumstances and various of these are mentioned as appropriate throughout the book.

There are broader connections between statistics and matters forensic which could perhaps be covered by the title 'forensic statistics' and which are not covered here, except briefly. These might include the determination of a probability of guilt, both in the dicta 'innocent until proven guilty' and 'guilty beyond reasonable doubt'. Also, the role of statistical experts as expert witnesses presenting statistical assessments of data or as consultants preparing analyses for counsel is not discussed, nor is the possible involvement of statisticians as independent court assessors. A brief review of books on these other areas in the interface of statistics and the law is given in Chapter 1. There have also been two conferences on forensic statistics (Aitken, 1991, and Kaye, 1993a) with a third to be held in Edinburgh in 1996. These have included forensic science within their programme but have extended beyond this. Papers have also been presented and discussion sessions held at other conferences (e.g., Aitken, 1993, and Fienberg and Finkelstein, 1996).

The role of uncertainty in forensic science is discussed in Chapter 1. The main theme of the book is that the evaluation of evidence is best achieved through consideration of the likelihood ratio. The justification for this and the derivation of the general result is given in Chapter 2. A correct understanding of variation is required in order to derive expressions for the likelihood ratio and variation is the theme for Chapter 3 where statistical models are given for both discrete and continuous data. A review of other ways of evaluating evidence is given in Chapter 4. However, no other appears, to the author at least, to have the same appeal, both mathematically and forensically as the likelihood ratio and the remainder of the book is concerned with applications of the ratio to various forensic science problems. In Chapter 5, transfer evidence is discussed with particular emphasis on the importance of the direction of transfer, whether from the scene of the crime to the criminal or *vice versa*. Chapters 6 and 7 discuss examples for discrete and continuous data, respectively. The final chapter, Chapter 8, is devoted to a review of DNA profiling, though, given the continuing amount of work on the subject, it is of necessity brief and almost certainly not completely up to date at the time of publication.

In keeping with the theme of the Series, *Statistics in Practice*, the book is intended for forensic scientists as well as statisticians. Forensic scientists may find some of the technical details rather too complicated. A complete understanding of these is, to a large extent, unneccesary if all that is required is an ability to implement the results. Technical details in Chapters 7 and 8 have been placed in Appendices to these chapters so as not to interrupt the flow of the text. Statisticians may, in their turn, find some of the theory, for example in Chapter 1, rather elementary and, if this is the case, then they should feel free to skip over this and move on to the more technical parts of the later chapters.

The role of statistics in forensic science is continuing to increase. This is partly because of the debate continuing over DNA profiling which looks as if it will carry on into the foreseeable future. The increase is also because of increasing research by forensic scientists into areas such as transfer and persistence and because of increasing numbers of data sets. Incorporation of subjective probabilities will also increase, particularly through the role of Bayesian belief networks (Aitken and Gammerman, 1989) and knowledge-based systems (Buckleton and Walsh, 1991; Evett, 1993b).

Ian Evett and Dennis Lindley have been at the forefront of research in this area for many years. They have given me invaluable help throughout this time. Both made extremely helpful comments on earlier versions of the book for which I am grateful. I thank Hazel Easey for the assistance she gave with the production of the results in Chapter 8. I am grateful to Ian Evett also for making available the data in Table 7.3. Thanks are due to The University of Edinburgh for granting leave of absence and to my colleagues of the Department of Mathematics and Statistics in particular for shouldering the extra burdens such leave of absence by others entails. I thank also Vic Barnett, the Editor of the Series and the staff of John Wiley and Sons, Ltd for their help throughout the gestation period of this book.

Last, but by no means least, I thank my family for their support and encouragement.

Preface to the Second Edition

In the Preface to the first edition of this book it was commented that the role of statistics in forensic science was continuing to increase and that this was partly because of the debate continuing over DNA profiling which looked as if it would carry on into the foreseeable future. It now appears that the increase is continuing and perhaps at a greater rate than in 1995. The debate over DNA profiling continues unabated. We have left the minutiae of this debate to others, restricting ourselves to an overview of that particular topic. Instead, we elaborate on the many other areas in forensic science in which statistics can play a role.

There has been a tremendous expansion in the work in forensic statistics in the nine years since the first edition of this book was published. This is reflected in the increase in the size of the book. There are about 500 pages now, whereas there were only about 250 in 1995, and the bibliography has increased from 10 pages to 20 pages. The number of chapters has increased from 8 to 14. The title remains the same, yet there is more discussion of interpretation, in addition to new material on evaluation.

The first four chapters are on the same topics as in the first edition, though the order of Chapters 2 and 3 on evaluation and on variation has been reversed. The chapter on variation, the new Chapter 2, has been expanded to include many more probability distributions than mentioned in the first edition. As the subject has expanded so has the need for the use of more distributions. These have to be introduced sooner than before, hence the reversal of order with the chapter on evaluation. Chapter 4 has an additional section on the work of early twentieth-century forensic scientists as it has gradually emerged how far ahead of their time these scientists were in their ideas. Three new chapters have then been introduced before the chapter on transfer evidence. Bayesian inference has an increasing role to play in the evaluation of evidence, yet its use is still controversial and there have been some critical comments in the courts of some of its perceived uses in the legal process. Chapter 5 provides a discussion of Bayesian inference, somewhat separate from the main thrust of the book, in order to emphasise its particular relevance for evidence evaluation and interpretation. Appropriate sampling procedures are becoming ever more important. With