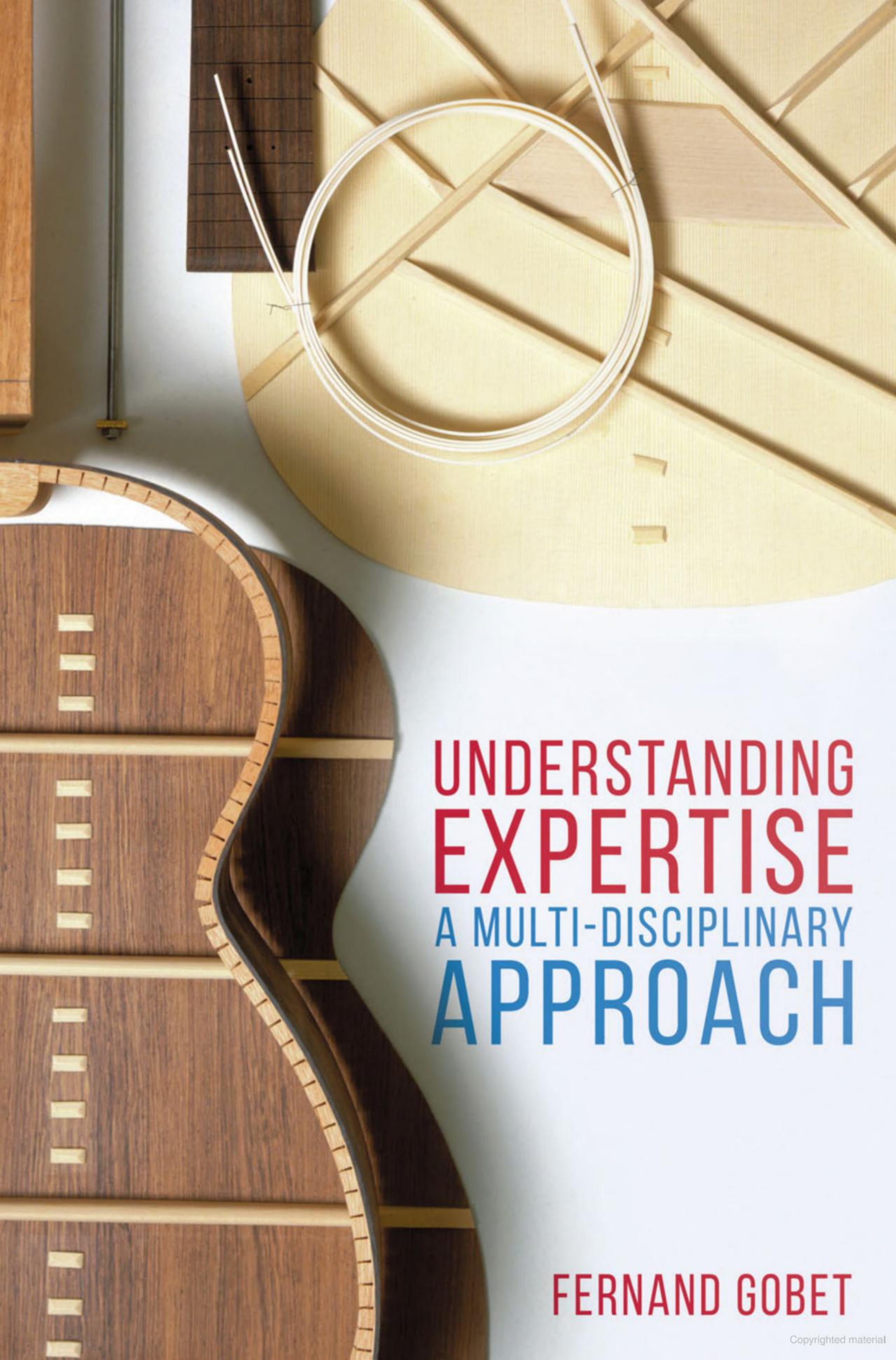

UNDERSTANDING EXPERTISE
A MULTI-DISCIPLINARY APPROACH

FERNAND GOBET

Understanding Expertise

A Multi-Disciplinary Approach

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University of Liverpool

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Preface

Writing this book, my fifth book on expertise, has been extremely challenging, but also very rewarding. My first two books on this topic were monographs on perception and memory in chess. My third book expanded the horizon somewhat and provided a systematic review on research carried out on board games. Many games were discussed (Go, checkers, awele and so on), but the focus was still on chess, since it was by far the board game having most contributed to the scientific literature. My fourth book, published in 2011 in French, was more ambitious and dealt with the whole field of the psychology of expertise. As a reflection on the evolution of my own scientific views, a considerable part of that book was devoted to the notion of talent.

The book you are holding in your hands is even more ambitious – with hindsight and considering the delay in finishing it, it was probably too ambitious. The idea was both to cover more domains of expertise than in the 2011 book (in particular, sports, music and medicine are discussed in more breadth and detail), and to address the question of expertise from multiple academic disciplines. Specifically, in addition to psychology, my own field, the book discusses expertise from the point of view of neuroscience, sociology, artificial intelligence and philosophy. Addressing these topics has required discovering entire new literatures and has taken me way beyond my comfort zone. It has also challenged some of the views I had held for decades. I had always found it surprising that nobody had written such an integrative, single-authored book before about expertise. Now, I know why… In any case, the experience has been extremely enriching.

Three intellectual tensions are omnipresent in this book. First, there is the tension between talent and practice, nature and nurture. My first intension was to downplay this aspect, but this was simply not possible. In particular, in recent years wars have been raging between the proponents of the extreme positions of the nature and nurture debate, in particular but not exclusively on the issue of deliberate practice, and this simply could not be ignored. As a student much influenced by Jean Piaget's thought on development and his middle ground approach in the nature-nurture debate, I had always thought that such extreme positions were absurd and had fully disappeared from the scientific horizon. I was right on the first point, but totally wrong on the second!

Second, some fields focus on the positive aspects of experts (superior memory, world records, inextinguishable creativity and so on) while others focus on their failings (arbitrary criteria for selection, inept predictions, lack of understanding of complex situations, arrogance and so on). In general, expertise is defined by performance in the first case and by society in the second. While there is some overlap between these two definitions, this overlap is far from being perfect.

Third, there is the tension between unlimited rationality and bounded rationality. Do humans make optimal decisions given the available information, or do they make systematic mistakes due to cognitive limits such as the limited capacity of short-term memory and the bottleneck of attention? Expertise is an ideal domain for studying this question, and the answers will clearly support the idea of bounded rationality.

A difficulty in writing this book is that there is a huge literature on expertise in each discipline, with little communication between them. For example, the literature on the sociology of expertise largely ignores the literature on the psychology of expertise, and the indifference is reciprocal. Given the amount of the material available – most of which is fairly recent – only snapshots of the relevant research can be given in this book. Inevitably, I have been biased in my selection of the material. While I have tried to provide a balanced sample, there is no doubt that I have tended to choose the topics I had researched myself directly or those that I found interesting. To compensate for this, numerous pointers to the respective literatures will be provided in the "Further Reading" sections.

As is typical of reviews or monographs on expertise, there is a fair amount of material on chess. In addition to chess being one of my topics of research, there are also scientific reasons for this. Historically, chess has dominated research into expertise. This is because it offers a relatively manageable but still complex task environment, and because it is nearly unique in expertise research in providing a reliable, quantitative, internal and thus ecologically valid measure of skill, the Elo rating (Elo, 1978). In addition, most of the phenomena identified with chess have been found to generalise to other domains. Thus, chess can be considered as a good model for expertise in general.

The economic and societal implications of a better understanding of expertise are considerable, and there are potentially serious implications for policy. One advantage – well worth the pains – of addressing expertise from the vantage point of multiple disciplines is that parallels and contradictions become evident between them. This allows one to derive some interesting prescriptions for education and other applications.

Finally, I should mention that I have carried out research on expertise for more than 20 years, mostly from the point of view of psychology. One consequence is that I tend to focus on the individual rather than on other levels such as brain structure, group or society. I think this intellectual bias is appropriate for studying expertise; ultimately, the entity being identified as an "expert" is an individual, although of course other levels of analysis are important as well. A second consequence is that I do have strong views about various aspects of expertise. I thought it would be more interesting for the reader to read a text that is personal, if sometimes opinionated, than to read an asepticised account. While I have tried to provide an objective account of divergent opinions, I have not hesitated to criticise them squarely when I thought the criticism was fair.

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List of Abbreviations and Acronyms

ACT-R	Adaptive Character of Thought – Rational
AI	artificial intelligence
AP	absolute pitch
CHREST	Chunk Hierarchy and REtrieval STructures
DP	deliberate practice
EPAM	Elementary Perceiver and Memorizer
g	general intelligence
GPS	General Problem Solver
IQ	intelligence quotient (used as a measure of intelligence in intelligence tests)
LTM	long-term memory
LTWM	long-term working-memory theory
ms	millisecond
NSS	Newell, Shaw and Simon (chess program)
SD	standard deviation
SOS	satisfaction of search
STM	short-term memory

Chapter 1

Introduction

1.1 Preview of Chapter

We live in a complex environment, where new technological developments regularly challenge our wits. With the development of the Internet, the amount of information that is available has increased exponentially over the last decade. It is therefore essential that we improve our understanding of the way people learn to cope with these challenges. In the last century or so, a tremendous amount of information has been acquired regarding learning in psychology, neuroscience, education, sociology and other fields, with a substantial portion derived from research into expertise. The aim of this book is to review the most important results stemming from this line of research and to evaluate their implications for society. In particular, we will be interested in the educational methods that have benefited from expertise research and in the implications that this research has on how society can develop ways to help citizens cope with these new challenges.

A good way to start is to illustrate, with a few examples, what we mean by experts. A list of top-level experts would include Wolfgang Amadeus Mozart in music, Marie Curie in science, Magnus Carlsen in chess, Bill Gates in business and Jessica Ennis-Hill in sports. A list of more ordinary experts would include a physician, an engineer, a lawyer but also a baker, a florist and a nurse.

From the outset, we face a few central questions on the nature of expertise. The most obvious is: what is expertise? We will spend some time discussing some of the many definitions that have been proposed and evaluating the extent to which they are successful. This will lead to a working definition that we will use in most of this book. Another important question relates to the reasons why it is important to study expertise. We will see that there are both basic scientific reasons and more applied ones. However, before we address these questions, we need to clear up an important issue about the dual meaning of the word "expertise".

1.2 The Dual Meaning of the Term "Expertise"

Whatever the detail of the definitions, which we will consider in the next section, one must recognise from the outset that the term "expertise" has two basic meanings, which are not necessarily consistent with each other. For example, the *Oxford Talking Dictionary* (1998) defines expertise as "Expert opinion or knowledge; know-how, skill, or expertness in something". The first part of the definition emphasises knowledge or even opinion – *knowing-that*. The second part emphasises skill – *knowing-how*, as indeed mentioned in the definition. This is a fundamental divide reflected in several of the fields we will consider in this book. On the one hand, sociology, law and – to some extent – philosophy are more interested in the first part of the definition (knowing-that). On the other hand, psychology, neuroscience and education essentially use the second part of the definition (knowing-how). Interestingly, some languages such as French accept only the first meaning of the term "expertise" in everyday language.

These two meanings raise the irksome question as to whether they are related, and indeed whether it makes sense to devote a book to expertise as a single concept. This book will argue that this is not only a meaningful endeavour but also an important one. Bringing together traditions of research that have focused on either meaning of the word will help integrate two bodies of knowledge that have essentially evolved independently. It also raises new and important questions that will spur new research and bring about new applications.

1.3 Definitions of Expertise

Having cleared up the question of the two basic meanings of "expertise", we can consider some of the definitions of expertise that have been proposed in the literature. Note that not all definitions neatly fit with the two meanings we have just discussed.

Intuitively, the term "expertise" brings to mind individuals such as physicians, engineers, chess masters and lawyers. Most people would also consider that good examples of experts are offered by the pundits (such as academics, journalists or business consultants) who proffer their views about their area of expertise (and even sometimes well beyond) on TV/radio and in newspapers. But what about occupations such as bricklaying and cigar making, or abilities such as language and walking, which most people carry out fluently? Obviously, some activities are more likely to be labelled as "expertise" than others. Is this reasonable or is it just a reflection of the prejudices of our society?

In research papers, expertise is often defined using experience and the amount of time an individual has spent in a domain. Unfortunately, while the amount of dedicated practice predicts expertise fairly well (see Chapter 8), experience in itself is often a poor predictor of true expertise (Ericsson et al., 1993; Meehl, 1954; Richman et al., 1996). Everybody knows amateur tennis players or pianists who fall short of expert performance despite having practised their favourite activity for years. In fact, there is direct empirical evidence from research on clinical expertise (Meehl, 1954) and chess (Gobet et al., 2004) indicating that the correlation between expertise level and the number of years spent in a field is weak.

Another reasonable approach is to use diplomas: PhDs, honorary titles and certificates from official professional associations. There are at least four weaknesses with this approach. First, diplomas are often based not only on an objective measure of performance but also on sociocultural criteria. Second, diplomas often do not test the skills that will be used later, but rather test declarative knowledge. This is the case, for example, in medical schools and most fields in universities (psychology is a case in point). Thus, future medical doctors are tested on their knowledge of anatomy, biochemistry and pathology, and not on their ability to diagnose and treat patients. Third, unless detailed grades are supplied, diplomas do not provide much information about the skill level obtained. Fourth, some individuals can be experts without formal qualifications. A striking example is provided by Epstein (1996), who showed that some AIDS activists had acquired considerable knowledge about microbiology and statistics, which, added to their knowledge of AIDS culture, allowed them to make substantial contributions to research. As Gallo, who co-discovered the human immunodeficiency virus (HIV) and who was originally lukewarm to AIDS activists' work, put it: "It's frightening sometimes how much they know and how smart some of them are" (Epstein, 1996, p. 338).

Some fields offer more reliable measures of expertise, measures that are also ecological, in the sense that they are part of the culture of the domain. Researchers of business expertise can use the wealth accumulated by different individuals; students of expertise in science can use the number of citations that scientists have accrued during their career; and researchers of writing expertise can use the number of books an author has sold. While having the advantage of being quantitative, these measures have shortcomings as well. In particular, they can be sensitive to factors unrelated to expertise, such as market fluctuations in business, popularity of a specific school of thought in science and fashion in literature.

In an ideal world – at least for scientific research – experts would be rank-ordered as a function of their level of expertise, or even better, they would have their expertise quantified. When absolute measures are involved (e.g. time to run 100 metres or the amount of weight that an athlete can lift), there is no debate, barring accusations of cheating. Rank ordering is used in sports such as football, where the International Federation of Association Football (FIFA) publishes a monthly ranking of national teams, using a rather byzantine formula. Tennis uses the ranking of the Association of Tennis Professionals (ATP): the sum of the best 18 results from the immediate past 52 weeks. From the point of view of expertise research, the ATP rating has two weaknesses. First, it measures skill only over the last year, and second, it only takes points won in entire tournaments into account and ignores the strength of the opponents as well as the outcomes of specific matches.

The best available system so far is the Elo rating (Elo, 1978), developed for measuring chess skill but now also used in other domains such as Scrabble and table tennis. The Elo rating takes into account both the outcome of a game (win, loss or draw) and the skill level of the opponent. It can be used after each game or match, producing a finely graded and up-to-date measure of skill. It also has the advantage that it is based on a sound mathematical model. Having such a quantitative measure is a real bonus, and this in fact partly explains why a considerable amount of research has been carried out on chess expertise. While researchers in most other domains of expertise have to satisfy themselves with coarse comparisons between novices, intermediates and experts, chess researchers can differentiate between a grandmaster with 2,620 Elo points and another with 2,680 Elo points, and even compute the expected outcome of a game between those two players.

Some researchers emphasise that expertise is something that can only be acquired with effort and intentionally, with a clear goal in mind (Bereiter & Scardamalia, 1993). This seems an unnecessary requirement. How expertise is acquired is of course important, but it does not seem wise to include this in a definition. Similarly, whether somebody is talented or not in a specific domain should not be part of the definition of expertise, not least because there is considerable disagreement about this question. We shall take up these issues in Chapters 7 and 8.

In a similar vein, it has been proposed that the hallmark of experts is that they display fluid behaviour, requiring few conscious decisions (Dreyfus & Dreyfus, 1988; Fitts, 1964). We shall see that this description captures expertise in some but not all situations. Moreover, it should also be pointed out that almost the opposite definition of expertise has sometimes been proposed. Bereiter and Scardamalia (1993, p.11) argue that "the expert addresses problems whereas the experienced nonexpert carries out practiced routines". A similar view is shared by Ericsson et al. (1993), who argue that just performing routine actions hinders the development of expertise, and that experts must deliberatively practice selected components of their skill. We will discuss this idea in considerable detail in Chapter 8 when dealing with *deliberate practice*.

The importance of knowledge has often been emphasised, in particular when human expertise is compared to the expertise (or the lack thereof) of computers. For example, it has been proposed that expertise is made possible by the acquisition of a large number of domain-specific patterns. While this is true in many domains (see Chapters 2 and 3), it seems prudent to not include putative *mechanisms* in the definition of expertise, in part because the nature of these mechanisms is still the topic of vigorous debate. In any case, investigating expertise will require reflecting on, and questioning, long-held views about the status of knowledge in cognition. An important question will be the link between knowledge and real-time cognitive processing. In intelligence research, these two forms of cognition are called *crystallised* and *fluid* intelligence, respectively (Cattell, 1971).

Based on the seminal work of de Groot (1965), who asked chess players of various skill levels to find the best move in a given chess position, Ericsson has repeatedly emphasised (e.g. Ericsson, 1996a; Ericsson & Smith, 1991a) that expert performance should be replicable in the laboratory, when tasks representative of the domain are used. For example, when studied in the laboratory and compared to non-experts, chess experts should find better moves, physicists should provide better solutions to physics problems and medical doctors should provide better diagnoses. As we shall see in this book, this is in fact what has been found in the three examples just given, and indeed in most (although by no means all) domains of expertise. Thus, Ericsson's requirement seems a valid one, at least with domains where it is feasible to set up laboratory tasks that are ecologically valid. But this is not always possible. A counter-example is expertise in developing novel and ground-breaking scientific theories in physics; by definition, such events are rare, and thus unlikely to be captured in the laboratory.

Finally, we would be remiss to not mention some definitions where the social aspects of expertise play a central role. These definitions emphasise that "expertise" is a label that society or other groups give to individuals, sometimes irrespectively of the real competences of these individuals. Support for this view comes from the fact that selection criteria differ from one domain to the next, and indeed even differ within a domain (Sternberg, 1997). Labels can be official, such as university and professional titles, or informal, such as the label of the "local technology wizard", but this is immaterial when it comes to societal recognition. Stein (1997) argues that the term "expertise" can only be used within a specific context. According to him, it is incorrect to say that expertise resides solely in the expert: while individual knowledge and skills are obviously important, these gain their meaning only within the context provided by the social system of which the expert is a part. We will take up these issues in Chapters 11 and 12 when dealing with the social aspects of expertise and the sociology of professions.

In most of this book, we will define an expert as somebody who obtains results that are vastly superior to those obtained by the majority of the population. This definition has the advantage that it can be applied recursively and that we can define a *super-expert*: somebody whose performance is vastly superior to the majority of experts (Gobet, 2011).[1] This definition also has the advantage of providing a means to deal with domains where most individuals have a high level of natural ability (e.g. language, walking). It is still possible to identify an expert in language (e.g. somebody who possesses a large vocabulary) and an expert in walking (e.g. somebody who has won an Olympic medal in the 20 km race walking event). Indeed, even with an ability as basic as breathing, it could be argued that practitioners of hatha yoga are experts, in that they have mastered breathing techniques unknown to most people. Finally, this definition can be applied to the two meanings of "expertise" we have highlighted earlier. The application is trivial with the *know-how* meaning: we can simply observe whether an expert does better than a non-expert. Does Lionel Messi dribble more successfully than a third-division player, or does an

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[1]A super-expert might correspond to what is sometimes called a "genius".

experienced surgeon operate better than a newcomer? The application is more delicate, but still possible, with the *know-that* meaning. The difficulty is not in testing the amount of knowledge – simple questionnaires can do this – but in the fact that knowledge itself can be of variable quality. For example, we would doubt the scientific quality of the knowledge used by an astrologer, but not by a civil engineer. This issue will be dealt with at great length in Chapter 12.

1.4 Why Study Expertise?

The study of expertise is important for society in several ways. First, it sheds important light on learning and the acquisition of knowledge, which can be used to develop better methods of instruction and training. Given the pace at which technology advances in our society, this is a significant contribution. For example, research on physics and mathematics expertise, together with other studies, has led to the development of artificial tutoring systems in mathematics that perform better than human teachers (see Chapter 8).

Second, research on expertise can lead to better ways of coaching experts. The clearest illustration of this comes perhaps from sport and music. In athletics, world records are improved every year due to better training techniques, and the difference between current and previous achievements is sometimes stunning. The winners of Olympic medals in the marathon one century ago recorded times similar to today's amateur runners. In swimming, the seven world records that earned Mark Spitz as many gold medals at the Munich Olympic Games in 1972 would not have been sufficient for qualification for the semi-finals in the 2008 Beijing Olympic Games.

Third, research on human expertise can inform the development of artificial expert systems performing at high or even human-like levels, as we shall see in Chapter 14. Expert systems are much cheaper, do not tire and do not move to other jobs – considerable advantages from the point of view of industry. Thus, expert systems can make valuable contributions to the economy.

With respect to cognitive psychology, research on expertise has shed important light on human cognition, and several general cognitive mechanisms have first been identified in expertise research. These include the role of pattern recognition in decision making and problem solving, progressive deepening and selective search. (We will discuss these mechanisms in detail in Chapter 4.) Thus, just as neuropsychology illuminates human cognition by studying a "special" population characterised by brain damage, expertise research provides critical information on cognition by focusing on individuals who go beyond the limits that mar most of us. In both cases, looking at an atypical population offers a unique window on typical cognition.

Positive psychology, which is now a very influential approach in psychology, was created from the observation that most psychology devoted all its energy to negative aspects of human psychology, such as pathology, while ignoring its more positive aspects (Linley et al., 2006; Seligman & Csikszentmihalyi, 2000). By contrast, positive psychology focuses on hope, optimism and other human virtues. It might be worth emphasising that research on expertise, which focuses on humans' creativity and their potential to achieve extraordinary performances, had unequivocally anticipated at least some of the claims of positive psychology.

1.5 Preview of Book

The following chapters deal with the psychology of expertise. Chapter 2 focuses on perception and categorisation. It shows that *perception* lies at the heart of expertise: experts literally "see" things differently compared to novices, enabling them to categorise situations and problems better. Chapter 3 argues that this superior perception is due to the vast amount of *knowledge* that has been stored in *long-term memory* (LTM) during the years of practice necessary to reach expertise. Numerous theories have been developed to explain expert memory, and this chapter reviews the main candidates.

In Chapters 4 and 5, we shall see how these differences in perception and knowledge affect *problem solving* and *decision making*. They also affect experts' *intuition*, *insight* and *creativity*, topics of Chapter 6. In all cases, non-cognitive factors are involved as well. These include *personality* and *intelligence*, which are covered in Chapter 7. This chapter examines different approaches, mostly from differential psychology, that defend the role of *talent*, and it also addresses the issue of *gender difference*s. In domains such as mathematics, science and chess, men vastly outperform women; is the origin of these differences social or biological? Finally, the chapter examines the hypothesis that creativity might benefit from *psychopathologies* such as manic depression and schizophrenia. When discussing these issues, these chapters provide an overview of the *key empirical results*, the *methods* used to obtain these results, and the *main theories* developed to explain them.

Chapter 8 covers the links between expertise, learning and education. It is concerned with four broad issues. First, it addresses the implications of theories based on talent for education. Second, it discusses the role of *practice* in acquiring expertise, and what theories focusing on practice tell us about the *training of experts*. If the theories presented in Chapters 2, 3 and 4 are correct, then it should be possible to isolate the components of *knowledge* that experts must acquire and design instruction and training methods that optimise their transmission to budding experts. Suitable practice schedules can then be designed and optimal feedback can be provided. In the extreme case, aspects of coaching could be automated with *intelligent tutoring systems*. Great attention will be devoted to the *deliberate practice* framework, which has been very influential in recent years. Proponents of *deliberate practice* argue that there is no empirical evidence for the role of talent in the development of expertise, and this claim will be discussed. The third issue addressed in this chapter is that of *transfer*. Do skills acquired in one domain transfer to others?

How do some experts appear to move to a different domain of expertise seamlessly, for example from being a biochemist to university vice-chancellor, while others fail to make such transitions? Finally, the chapter addresses the question of *expert learners* and *expert teachers.* Are some individuals just better than the majority at acquiring new information? Are some individuals particularly efficient at transmitting information to others? If so, what does this tell us about education in general?

Chapter 9 covers expertise across the life span. How does expertise develop with children? What are the respective roles of knowledge (including strategies) and biological maturation? What light do *savants* throw on expertise in general? Is the talent of *gifted children* limited to a single domain? At the other side of the life span, we will consider how *ageing* affects expertise, and whether expertise acts as a moderating variable in the ageing process. We will also consider how the careers of creative people evolve across time.

Chapter 10 addresses the links between expertise, biology and neuroscience. It discusses the influential theory proposed by Geschwind and Galaburda (1987), which ties together data from psychopathology (e.g. *dyslexia* and *autism*), developmental neuroscience and expertise in a large variety of domains including mathematics, visual arts and music. Recently, important discoveries have been made with the advent of novel *brain imaging techniques* (e.g. functional magnetic resonance imaging) as well as new developments with older techniques (e.g. electro-encephalography), and this chapter reviews the most important of them. These cover a large variety of expertise domains, most notably *sports* and *music*. The key notion of *brain plasticity*, which impinges on the interpretation of some of these data, is also examined. Finally, a better understanding of the biological mechanisms underpinning expertise raises the possibility of *creating new drugs* that will speed up the development of experts and enhance their performance. How far are we from this Brave New World?

Chapters 11 and 12 deal with expertise and its place in society. In some domains, the *distinction between experts and non-experts* is obvious. If one doubts that Maryam Mirzakhani, who in 2014 was the first woman, Muslim and Iranian to win the prestigious Fields Medal, is an expert in mathematics and more specifically the symmetry of curved surfaces, one can always try to identify errors in her proofs. However, as we have just seen, there are other domains – perhaps most domains in "real life" – where the definition of expertise is controversial. More generally, there is the issue that *expertise criteria* vary from one domain to the next, and that criteria are sometimes used inconsistently within the same domain of expertise. This particularly applies to *the professions*, which are the main kind of institutionalised expertise in industrialised countries (most notably lawyers and the medical profession).

How then are experts *selected* and *labelled* by society? Are official titles (such as those awarded by universities) always necessary? To what extent do *specific contexts* create new types of expertise and new experts? Is expertise just the product of an arbitrary selection from a particular group? What are the specific practices that enable social and cultural authority? Do experts in Scientology and astrology have the same status as experts in neuroscience and astronomy? What is the *role of scientific knowledge* in validating experts? Are today's experts tomorrow's non-experts? These considerations are answered by results from sociology research.

Another key topic of these chapters concerns the *power of experts*, at least in industrialised societies. Directly or indirectly, experts played a role in the recent global financial crisis either by condoning financial practices that were – with the benefit of hindsight – too risky or failing to predict the consequences of these practices on the dynamics of markets. Similarly, experts have a considerable impact on *political decisions* (consider, for example, global warming or the 2009 swine flu pandemic), even though the science itself is a matter of dispute amongst experts. This raises complex questions about *experts' legitimacy and accountability.*

These chapters also address the extent to which it is possible to *communicate expert knowledge* – an issue that is crucial in legal settings, for example with expert testimony. Authors such as Luhmann (1995) have argued that experts essentially cannot communicate knowledge outside their constituency. This is because social communication systems each make sense of their environment using their own code. Others, such as Mieg (2001), have been more sanguine about experts' ability to do so. Finally, the chapters address the question as to how the *mass media* and more recently the *Internet* affect the way expert knowledge is communicated.

The final theme addressed in these chapters is the issue of the legal status of the expert. There are vast differences in the way experts are *defined and selected in different legal systems.* These chapters compare and contrast practices in the common law jurisdictions of Anglo–American courts with the civil law jurisdictions within continental Europe. Key questions include an analysis of current systems of *appointment of expert witnesses* and, more generally, of the designation of someone as an "expert". Another issue is that the legal coding of information will be different to that used, for example, in engineering. As a consequence, *expert opinion* will have a different meaning and significance within the legal system to those within the domain from which the expertise originated, often creating serious misunderstandings and distortions.

The discussion of the philosophy of expertise in Chapter 13 will allow us to revisit some of the central questions of this book: the question of *rationality*, the nature of *knowledge* acquired by experts (*knowing-that* and/or *knowing-how*), and the nature of *scientific knowledge.* Anticipating the following chapter, it will also address the *philosophical implications* of artificial systems emulating human experts.

A motivation for some of the research discussed in Chapters 2 and 3 was that a sound understanding of the cognitive processes underlying expert behaviour should make it possible to develop *artificial systems* that are able to perform as well as, or even better than, human experts. The field of *expert systems* is a recognised and active discipline of computer science, and there are a number of expert systems developed to the point that they are crucial to some industries (for example, banking and geology). Chapter 14 discusses *strengths and weaknesses of such systems* as well as other related issues. What are the differences between expert systems and human experts? How is knowledge elicited from experts? Can experts really communicate their perceptual and procedural knowledge? What do expert systems teach us about *human expertise and human psychology* more generally?

Finally, the conclusion weaves together several of the strands that were discussed in previous chapters. It proposes a synthesis, highlighting the issues that should be addressed in future research.

1.6 Chapter Summary

This chapter started with a discussion of the two key meanings of expertise: knowing-that and knowing-how. It then considered a number of definitions of expertise, each emphasising a different aspect (e.g. type of measurement or place in society). It was noted that many of these definitions suffer from weaknesses. A fair amount of space was devoted to the question as to why we should study expertise. The main reasons were: the development of better methods for coaching and instruction in general, the prospect of building artificial-intelligence programs that can emulate human experts and to improve our understanding of human cognition.

1.7 Further Reading

Several edited books provide worthwhile overviews of the various ways expertise has been studied. Chi et al. (1988), Ericsson and Smith (1991b), Ericsson (1996b) and Staszewski (2013a) focus on cognitive psychology, although other viewpoints are occasionally discussed. Feltovich et al. (1997) discuss both human and machine expertise, with a special interest in the role of context. Ericsson et al.'s handbook (2006) provides a comprehensive overview of the psychology of expertise, with a strong emphasis on deliberate practice. Another handbook (Simonton, 2014) focuses on extreme forms of expertise – genius.

Chapter 2

Perception and Categorisation

2.1 Preview of Chapter

How can experts immediately "see" the right solution to a routine problem, while non-experts fumble hopelessly? The short answer is simple, although the details are much more complicated: in nearly all domains, expertise relies considerably on perception, which allows experts to rapidly categorise a problem. This perception is not innate but the product of extensive study and practice. A considerable amount of research has been carried out on this topic, starting with de Groot's (1965) seminal research on chess players, originally published in Dutch in 1946.

The chapter covers perception and, to a lesser extent, categorisation. It starts with de Groot's studies on chess, and then covers the role of perception in medical expertise, sport and music. The concepts of holistic perception and anticipatory schemata are also discussed. Finally, the chapter briefly addresses the topics of perceptual learning, perceptual expertise and categorisation. Note that there is a fair amount of conceptual overlap between this chapter and the next on memory. Whilst somewhat artificial, devoting one chapter to "perception and categorisation" and the other to "memory" has the advantage of providing a structured presentation of the material.

2.2 De Groot's Seminal Research

Perhaps the most striking aspect of expertise is that experts, very rapidly, see the key features of a scene or a problem situation, so long as the material comes from their domain of expertise. This phenomenon was experimentally established by Adriaan de Groot in his doctoral dissertation (de Groot, 1965). In a first experiment, de Groot gave chess players of various skill levels a chess position and asked them to select what they thought was the best move whilst thinking aloud. As expected, better players tended to find better moves. However, surprisingly, an analysis of the verbal protocols did not identify clear-cut differences in the structure of search. That is, better players did not search deeper, examine more moves or display a different way of searching. However, strong players very rapidly identified promising solutions, unlike weaker players. In fact, de Groot noted that the world champion had a better understanding of the position after 5 seconds than a strong amateur after 15 minutes! Thus, the first few seconds of seeing a position are critical for its understanding. De Groot concluded that perception must be a key component of chess skill, and presumably other skills.

To test this hypothesis, de Groot designed a simple experiment that was destined to have a tremendous impact on the psychology of expertise. He presented a chess position taken from an unknown game for a short amount of time (from 2 seconds to 15 seconds), then removed it from view and asked the participant to reconstruct it; the skill effect was striking. While a top grandmaster could recall almost the entire position, a strong amateur would struggle to remember 50 per cent of the pieces. Although this experiment is classified nowadays as a *memory* experiment (see Chapter 3 for an in-depth discussion), it is important to realise that de Groot considered it as a *perception* experiment, aimed at understanding what chess masters were *seeing* during the brief presentation of a position.

In some variations of the experiment, de Groot asked his players to think aloud when seeing an unknown position for a brief amount of time (e.g. 5 seconds). The protocols were collected in three different conditions: when the position was presented, immediately after the presentation or 30 seconds after the presentation (de Groot, 1965; de Groot & Gobet, 1996). A detailed analysis of the protocols revealed that, rather than seeing individual pieces, experts see large complexes, in which perceptual and dynamic aspects are interwoven. In fact, they rarely see static constellations of pieces, but rather notice dynamic possibilities, such as threats and potential moves and even sequences of moves. We will take up this hypothesis in Section 2.4.

Skill differences in perception were later corroborated in an experiment where chess masters' and amateurs' eye movements were recorded when they were looking at a position for 5 seconds (de Groot & Gobet, 1996). As shown in Figure 2.1, masters' fixations were shorter and less variable than those of amateurs. Masters also fixated on more squares than amateurs, and tended to look more often at the important squares, as defined by a technical analysis of the positions. This last result cannot be explained away by the fact that masters looked at more squares, because the effect remains when the total number of fixated squares is controlled for statistically. Interestingly, de Groot and Gobet also found that masters fixated more on the intersection of squares, which supports the idea that they were looking at groups of pieces rather than at pieces individually. This result has been replicated by Reingold et al. (2001), who used a check detection task rather than a memory task.

In an elegant experiment, Reingold et al. (2001) tried to estimate the visual span of chess players of different skill levels. To do so, they combined the change blindness paradigm (also known as the flicker paradigm) with the gaze-contingent window paradigm. In the change blindness paradigm, a picture is repeatedly presented in alternation with a modified version of

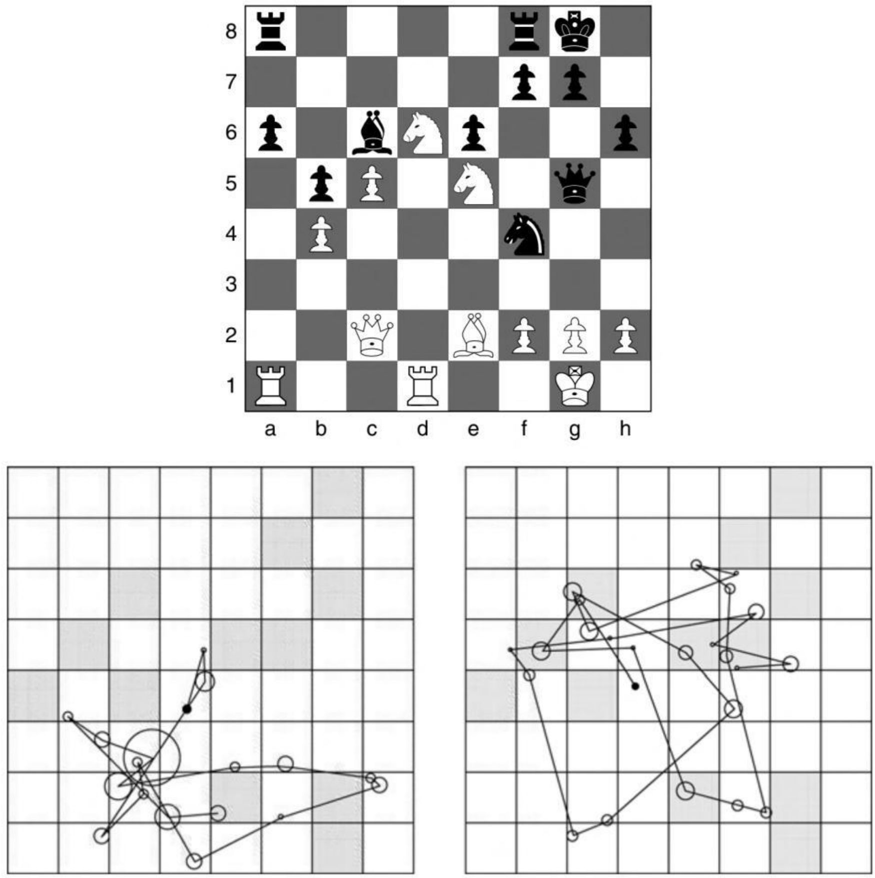

Figure 2.1 Eye movements during a 5-second presentation of a chess position. On the left, the eye movements of an amateur. On the right, the eye movements of a master. The diameter of the circles is proportional to the duration of the fixation. Important squares in the position are greyed. The first fixation is indicated by the black circle in the middle of the board.

Source: From de Groot, A. D., & Gobet, F. (1996). *Perception and memory in chess*. Assen: Van Gorcum. Copyright: F. Gobet.

this picture. Each picture is preceded by a flashed blank screen. The task is to identify the difference. This paradigm has shown that humans have great difficulties in detecting striking changes to objects and scenes (Rensink et al., 1997). In the gaze-contingent window paradigm, sophisticated eye-tracking software makes it possible to change the display in real time so that what is clearly visible to the participant (the "window") is modified as a function of what the eye fixates.

Reingold et al. used this methodology to study the extent to which randomising chess positions affects perception. After each eye movement, the window was centred on the fixation point, and grey blobs replaced chess pieces that lay outside the window. The change after the flicker modified the kind of piece located on a given square, and could happen either inside or outside the window. There were two independent variables: chess skill (novice vs. intermediate vs. expert) and configuration type (game vs. random). The dependent variable of interest was response time to detect the minor change in the position. Participants' visual span was determined by varying the size of the window after each trial and estimating the smallest window for which performance did not significantly differ in comparison to the baseline condition, where pieces outside the window were not replaced by blobs. Reingold et al. found that experts' visual spans were larger with structured positions, but not with random positions.

2.3 Medical Expertise

Eye movements have also been studied with professional experts, such as experts in radiology, a domain where a better understanding of expertise could have lifesaving implications. Radiologists take high-stake decisions, but their task is difficult as it necessitates the analysis of low-contrast and small features embedded in non-uniform backgrounds. The data collected using eye tracking have identified clear skill differences in perception between novices and experts (for reviews of literature, see Reingold & Sheridan, 2011; Taylor, 2007). Even with brief exposure times, radiologists are still able to detect a large proportion of abnormalities in an image. For instance, Kundel and Nodine (1975) found that expert radiologists could identify 70 per cent of the abnormalities when chest films were presented only for 200 ms. By comparison, with no limits in viewing time, they could identify 97 per cent of the abnormalities.[1] An important feature of brief-exposure studies is that there is not enough time for participants to make an eye movement, which means that successful identification of abnormalities requires the use of peripheral vision.

A number of studies have been interested in the pattern of eye movements when radiologists of varying skill levels scan an image. A comparison of novices' and experts' scan paths shows several important differences, which together point to more efficient scan paths for the experts and to the use of peripheral vision to guide search (e.g. Kocak et al., 2005; Krupinski, 1996; Krupinski

[1]The high percentage is not representative of real-life performance, where diagnosis hovers between 75 per cent and 95 per cent, which is low considering that 50 per cent is chance level (Groopman, 2007). Intra- and inter-observer variability is also high. Interestingly, the performance of automated computer diagnosis systems is around 80 per cent, but with different errors compared to humans. Computer-assisted diagnosis has tried to combine human and computer skills to reach higher-quality diagnoses.

et al., 2006; Manning et al., 2006). Experts tend to have fewer fixations, to use fewer but longer saccades, to cover a smaller portion of the image and to reach the abnormality faster, often within one second of viewing. In addition, Kundel et al. (2007) found that there is a negative correlation between first fixation of abnormality and accuracy (the participants fixating the abnormality faster tended to be more accurate). Interestingly, immediately after viewing the image, mammogram experts often display a long saccade in the direction of the abnormality. In general, expert radiologists show what Kundel and Wright (1969) call a circumferential scan pattern: they first get a general impression by scanning the image with a small number of long saccades that land in points that are wide apart in the display.

Several experiments have used the gaze-contingent window paradigm, which we have described earlier with chess. Kundel et al. (1991) compared a condition where nodules (small aggregations of cells on the lung that are about 3 cm long) could be seen only when fixated upon directly in foveal vision with a condition where they could also be seen in parafoveal and peripheral vision. The nodules were identified faster in the latter than in the former case. Moreover, an increase of the window size led to faster identification (Kundel et al., 1984). In line with these results, presenting the full image led to better performance than the presentation of segments of that image one at a time. Finally, accuracy is lower when participants are instructed to focus on one aspect or region of the image than when they receive no such instruction (free viewing). In total, these experiments support the role of peripheral vision in experts' scan of radiology images.

Two models have been proposed to explain experts' eye-movement patterns in radiology. The global-focal search model (Nodine & Kundel, 1987) proposes that, by comparing the image with their schemas of normal and abnormal radiographs, experts are able to rapidly create a landscape view of the picture. This view enables them to process information for a larger visual span than novices, and thus to scan the image more efficiently. Once deviations from the normal schemas and matches with abnormal schemas are identified, the experts scan the image in more detail with foveal vision.

The two-stage detection model (Swensson, 1980) proposes that experts have refined their perception with the acquisition of mechanisms that provide a filter to automatically point out features of the display that should be examined further. As noted by Reingold and Sheridan (2011), there is a clear similarity between these models and Chase and Simon's (1973a) chunking theory, which will be discussed at length in the next chapter.

The importance of parafoveal and peripheral information for finding relevant information has been demonstrated in other medical fields as well. Krupinski et al. (2006) provide data from telepathology, where participants examined virtual slides and had to decide which locations they would select for further analysis. Compared to medical students and pathology residents, practising pathologists moved their eye less often but had longer saccades. This was interpreted as being indicative of a more efficient scan path being used by practising pathologists. Some of the locations selected by the practising pathologists were never fixated, which strongly suggests that parafoveal and peripheral vision was used. In an experiment using tasks similar to laparoscopic surgery simulation, expert surgeons fixated fewer locations than novices (Kocak et al., 2005). Interestingly, in three basic laparoscopic tasks, experts tended to fixate the target but not the tool, which suggests that they were able to manipulate the tool with information from peripheral vision only.

2.4 Holistic Perception and Anticipatory Schemata

A classic question in psychology is whether perception is holistic – as for example argued by Gestalt psychology – or whether it can be accounted for by incremental, constructive mechanisms. Tikhomirov and Poznyanskaya (1966) argued that the eye movements of a chess player considering his next move supported the former view. By contrast, Simon and Barenfeld (1969) defended the view that these data could be explained equally well by a simulation program that was based on local aspects of the board position (e.g. relations of defence and attack between pieces). More recent simulation work with CHREST, a computer model based on the idea of chunking (see Section 3.11.4.2), is in line with Simon and Barenfeld's view. For example, Gobet and Chassy (2009) present simulations showing how the internal representation of a player can be explained by the progressive recognition of chunks and templates.

Authors such as Selz (1922) and de Groot (1965) postulated the existence of *anticipatory schemas.* These schemas comprise information that makes it possible to anticipate actions. A logical hypothesis is that these schemas should be more developed with experts, who should thus anticipate actions better. A series of experiments has tested this hypothesis with chess players (Ferrari et al., 2006), basketball players (Didierjean & Marmèche, 2005), car drivers (Blättler et al., 2010) and pilots of the French Air Force (Blättler et al., 2011). In general, these experiments support the notion of an anticipatory schema: rather than memorising a scene the way it was presented, experts tend to memorise it the way it will be in the near future. For example, in one of the driving experiments, participants were shown a video of a car driving in some direction. The video was then interrupted, and then resumed either at the point before the interruption, or at a different point. Participants' task was to estimate whether the resumption point of the video was at the same point as or at a different point than when it stopped. Both experienced and inexperienced drivers tended to remember the position of the car when the video was interrupted as being farther in the direction of movement than it actually was when the video resumed. However, the effect was stronger with experienced drivers, which supports the hypothesis that their anticipatory schemata were more developed.

2.5 Perception in Sport

Perceptual requirements vary considerably between different sports. They tend to be high in team sports and in sports such as football and badminton that include a moving object, and low in individual non-contact sports such as weight lifting, swimming and running. Perceptual requirements also vary depending on one's role in sport (Hodges et al., 2006). For example, in football, a goal-keeper, a defender and an attacker will direct their attention to different features of the game. Similarly, a player, a coach and a referee will develop different perceptual skills.

An added difficulty with sports, compared to more cognitive domains of expertise, is that perceptual skills must be linked to movements, with a few critical constraints: as time pressure is considerable, processing must be rapid, so players use only minimal cues most of the time; movements often incur a fair amount of coordination and must be executed rapidly and precisely; and players must keep in mind the possibility that their opponents might use deception tactics. As an example, consider a tennis player such as Venus Williams returning a serve. The ball travels so fast (115 mph; 185 km/h) that Williams has to decide on her response and initiate the movements before the ball is served; the movements include, at the minimum, moving to a specific location, and hitting the ball with the racket with suitable strength and spin. There is only about 300 ms between the time the ball is served and returned, and it has been estimated that the minimum time for the visual input to reach the visual cortex is 100 ms and the minimum time to initiate a motor response is 150 ms. To this, one must add the time to actually execute the movement. You can see that there is little time available for deciding which sequence of actions to carry out. Essentially, all relevant processing must happen automatically and subconsciously.

Considerable research has confirmed that elite athletes make both better and quicker decisions. Among other sports, the experimental evidence includes tennis (Wright & Jackson, 2007), football (Williams et al., 1993), cricket (Mueller et al., 2006) and badminton (Abernethy, 1988). Following de Groot's original work, experts' perceptual superiority has often been explained in the literature in terms of the knowledge they hold, and we will specify this knowledge in more detail in the chapter on memory. However, we must also deal with another plausible explanation: it could be the case that experts simply have better low-level perceptual abilities, such as static visual acuity, dynamic visual acuity and stereovision, perhaps for genetic reasons. A fair amount of research has been carried out in sport psychology between 1950 and 1980, and the answer appears to be negative: there is no correlation