The Neuroscience of Expertise

The Neuroscience of Expertise examines the ways in which the brain accommodates the incredible feats of experts. It builds on a tradition of cognitive research to explain how the processes of perception, attention, and memory come together to enable experts' outstanding performance. The text explains how the brain adapts to enable the complex cognitive machinery behind expertise, and provides a unifying framework to illuminate the seemingly unconnected performance of experts in different domains. Whether it is a radiologist who must spot a pathology in a split second, a chess grandmaster who finds the right path in a jungle of possible continuations, or a tennis professional who reacts impossibly quickly to return a serve, *The Neuroscience of Expertise* offers insight into the universal cognitive and neural mechanisms behind these achievements.

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The Neuroscience of Expertise

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CAMBRIDGE
UNIVERSITY PRESS

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University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

4843/24, 2nd Floor, Ansari Road, Daryaganj, Delhi – 110002, India

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107084599
DOI: 10.1017/9781316026847

First published 2017

Printed in the United Kingdom by TJ International Ltd, Padstow Cornwall

A catalogue record for this publication is available from the British Library.

ISBN 978-1-107-08459-9 Hardback
ISBN 978-1-107-44651-9 Paperback

To Esther

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Preface

When was the last time you were left scratching your head struggling to come to grips with what you had just seen? A good bet would be that you were witnessing an amazing performance by one of the very best performers in his or her field. You do not even have to witness Adele hitting note after note perfectly; or the world chess champion, Magnus Carlsen, who, blindfolded, plays a dozen opponents simultaneously and demolishes them; or the incredible Serena Williams, who continues to win Grand Slam tennis tournaments at such a rate that her current number of singles titles (21) will probably have increased by the time this book reaches the shelves. There is a good chance that if you go to a local music school, or a local chess or tennis club, you will find other people so exceptional at their craft that, watching them, you would be forgiven for thinking that some kind of trick or magic is involved. This book is devoted to these experts and the way their brain accommodates their exceptional performance.

Expertise is a fascinating topic because, among other reasons, understanding the ways in which experts achieve their incredible feats would satisfy our curiosity. However, it would also help us prepare better training programs for future experts, a necessity in today's world where almost any position requires extensive specialization and a developed set of skills. It is thus no wonder that the scientific study of expertise is as old as the science of psychology itself. These days, expertise is an established topic in psychology and a constituent part of any curriculum or textbook in cognitive psychology. In 2017 alone, three big handbooks on expertise are scheduled to appear. Yet, in a century marked by technical advances and the rise of neuroscientific research, this is the first book on the neuroscience of expertise, to the best of my knowledge.

Just like many other cognitive psychologists, I am excited by the wide availability of neuroimaging devices and recent technical advances in neuroscience. Neuroimaging techniques present an exciting way to obtain new insight into complex topics, such as expertise. They are, however, not a magic bullet, nor will they suddenly provide the answers that we have been seeking for more than a hundred years. It is unlikely that they will make the previous behavioral research redundant. I am a firm believer that in order to understand how something works, especially something as complex as experts' performance, one needs to draw from various sources of information. Neuroimaging data are too valuable to

pass by, and, as it happens, the traditional cognitive approach and the new neuroimaging techniques complement each other particularly well.

The book exemplifies why understanding the cognitive processes behind a phenomenon becomes crucial for understanding how the brain accommodates that phenomenon. *The Neuroscience of Expertise* builds on the traditional expertise research that demonstrates how basic cognitive processes, such as memory, attention, and perception, come together to enable experts' outstanding performance. You will understand why some athletes appear to have all the time in the world in domains where everything changes and moves quickly, why chess grandmasters can foresee the future without really looking more than a couple of moves ahead, and why radiologists need just a split second to realize that something is amiss in a radiological image. I can immediately disappoint readers who are hoping to find out that experts are somehow differently hard-wired. The cognitive capacities of experts, just like those of the rest of us, are limited. There are no superpowers and there are no supernatural shortcuts to becoming an expert. But the beauty of expertise lies exactly in the way that experts nevertheless circumvent their limited cognition to pull off their amazing feats. The end product of expertise may look mesmerizingly simple, even effortless, but the process requires a complex interplay between basic cognitive processes to make it work. That our brain is able to accommodate such complex machinery is a testament to its incredible adaptability.

The connection between the cognitive processes behind expertise and the way expertise is implemented in the brain is the overarching theme in the book. Expertise comes in many forms and guises but the basic principles are the same whether we talk about radiology, chess, or tennis. I have organized the book around these three domains because they mirror how we act in everyday life – usually perceiving the world (perception) and making sense of it (cognition), which precede acting on the environment (motor). Radiology is typical of **perceptual expertise**, the kind of expertise where we predominantly rely on our senses. Beside radiologists, in Chapter 2 I will examine a number of other perceptual experts, from sommeliers and perfumers to blind people who have well-developed tactile skills. Perception plays a role in chess, but to be good at it one also requires the ability to imagine and hold various possible strategies in one's mind. Chapter 3 is on **cognitive expertise** and features game board experts, exceptional memorizers, outstanding calculators, and taxi drivers. The next chapter, Chapter 4, examines **motor expertise** and includes experts in sports, music, and other fields involving movement, such as dance. These three chapters are preceded by the introductory first chapter, which defines experts and expertise, positions the field of expertise

in the wider context of cognitive neuroscience, and lays down the main principles behind the cognitive mechanisms behind expertise and the way the brain accommodates them. These principles will then be employed and expanded on throughout the rest of the book. In the fifth and final chapter, I not only summarize the common themes in the book, but also tackle a number of advanced topics, such as expertise and aging. A good part of the closing chapter, however, is devoted to examining what it takes to become an expert.

I wrote the book with undergraduate students in mind, who need a simple introduction to complex topics. This is particularly the case with cognitive and neuroscience topics, which are populated by numerous disjointed theories that make it difficult for students to grasp the essence of the work. I took great care to introduce basic concepts early in the chapter, explain them in simple terms, and only then to connect them with more advanced topics later in the chapter. These key terms have been highlighted when they are first mentioned in each chapter and have been collected in a glossary at the end of the book. Each chapter starts with a list of learning objectives and then introduces the main topics in the text. The main text also provides an overview of the brain's anatomical and functional properties, which is necessary for the understanding of the neural processes behind expertise. The major studies and the most important concepts have been illustrated with figures, some of them in color in the color plates situated in the middle of the book. The core ideas are then summarized and review questions, together with a list of recommended literature for further reading, have been provided at the end of the chapter. The book has a uniform feel not only because of this consistent chapter structure, but also because of the integrating framework it uses throughout the book – the connection between the cognitive processes behind expertise and the way they are accommodated in the brain.

Nevertheless, the book is modular in nature and each chapter can be read and taught separately. Repeating key terms from previous chapters and defining them anew is inevitable. I took great care, however, in adding only the necessary details at the beginning and then expanding them in the other chapters. For example, the term **chunking**, one of the central concepts in expertise, is briefly introduced in the first chapter, but it is then employed throughout the other three chapters dealing with different types of expertise. In the second chapter, on perceptual expertise, it is discussed in relation to another key concept, that of **holistic processing**. It is then dealt with in more detail in the third chapter, on cognitive expertise, as the term is mostly associated with the research on memory and board expertise. Finally, in the fourth chapter, on motor expertise, the reader

should realize that one can consider sequences of motor movements, also called **motor programs**, as constituting a special kind of chunk.

Instructors interested in adapting the text for their course can obtain additional material, which includes presentation slides with high-resolution figures, from a dedicated website for the book. The material also includes links to popular science articles used in the book, as well as a collection of links to the related content on the Internet. Beside students, my hope is that the book will be of use for the wider public curious about the way the brain enables expertise. The book is written in what I hope is a simple and engaging style with plenty of references from real life, popular culture, and sports. The content on the website dedicated to the book will be another valuable resource to such readers. I am easily found on the Internet and would be delighted to answer queries regarding the book.

Needless to say, this book, already a couple of years in the making, would have been impossible without the help of many people very dear to me. It would not have been possible without the patience of my wife, Esther, to whom this book is dedicated. For all the hours spent on this book which should have been used for so many other purposes, I apologize. I have exchanged countless drafts with Matthew Bladen, who was instrumental in wrangling the text into something resembling standard English, while making it difficult to work on the book in public without attracting attention, due to the often hilarious comments he left in the margin. Thanks for all the help and friendship, Strong Bad! Most of the images you will marvel at in the text are the work of my research assistant, Anna Stylianopoulou. She also read and commented on the manuscript, repunctuating where necessary, and showed tremendous patience in dealing with my many requests. My thanks also go to Nemanja Vaci and Wolfgang Wicher, who contributed to the creation of graphs, as well as Mario Graf, who checked the key terms and references. I am in debt to my colleagues Guillermo Campitelli, Robert Langner, and Luca Turella for their comments on earlier drafts of the book. They have undoubtedly made the book better. The same goes for the many researchers who have discussed their work with me, as mentioned in the book. Some of them were not only kind enough to give me permission to redraw their figures, but also provided me with their raw data. As always, any mistakes in the book are solely my responsibility, and I am happy to have them drawn to my attention – my email address can easily be found on the Internet. Finally, the folks at Cambridge University Press, Matthew Bennett, Brianda Reyes, and Valerie Appleby, were extremely patient with me and were helpful throughout the whole writing process. I am grateful to all of you, and I sincerely apologize to those whom I somehow managed to omit.

Abbreviations

A1 – primary auditory area
ACC – anterior cingulate cortex
AF – arcuate fasciculus
AG – angular gyrus

AON – action observation network
CFE – composite face effect
DLPFC – dorsolateral prefrontal cortex

DTI – diffusion tensor imaging
EEG – electroencephalography
FFA – fusiform face area
FG – fusiform gyri
fMRI – functional magnetic resonance imaging

IFC – inferior frontal cortex
IFE – inverted face effect

IPS – intraparietal sulcus
LOC– lateral occipital cortex
LTM– long-term memory

LT-WM – long-term – working memory
M1 – primary motor cortex
MCI – mild cognitive impairment

MEG – magnetoencephalography
MEP – motor-evoked potential
MRS – magnetic resonance spectroscopy

MT+ – motion center
MVPA – multivariate voxel pattern analysis
OFA – occipital face area
OFC – orbitofrontal cortex
PCun – precuneus

PET – positron emission tomography

PHG – parahippocampal gyrus
PMd – premotor cortex dorsal

PMv – premotor cortex ventral
PPA – parahippocampal place area

RSC – retrosplenial cortex
S1 – primary somatosensory cortex
S2 – secondary somatosensory area

SMA – supplementary motor area
SMG – supramarginal gyrus
SoS – satisfaction of search

STG – superior temporal gyrus
STM – short-term memory

STS – superior temporal sulcus

V1 – primary visual area
WM – working memory