

#### The Cambridge Handbook of the Neuroscience of Creativity

Historically, the brain bases of creativity have been of great interest to scholars and the public alike. However, recent technological innovations in the neurosciences, coupled with theoretical and methodological advances in creativity assessment, have enabled humans to gain unprecedented insights into the contributions of the brain to creative thought. This unique volume brings together contributions by the very best scholars to offer a comprehensive overview of cutting-edge research on this important and fascinating topic. The chapters discuss creativity's relationship with intelligence, motivation, psychopathology, and pharmacology, as well as the contributions of general psychological processes to creativity, such as attention, memory, imagination, and language. This book also includes specific and novel approaches to understanding creativity involving musicians, polymaths, animal models, and psychedelic experiences. The chapters are meant to give the reader a solid grasp of the diversity of approaches currently at play in this active and rapidly growing field of inquiry.

REX E. JUNG received his PhD in Clinical Psychology from the University of New Mexico with specialty training in clinical neuropsychology. He is a clinical professor in the Department of Neurosurgery at the University of New Mexico, and in private practice, with current duties focused around neuropsychological assessment during awake craniotomy. He has published research articles across a wide range of disciplines, including traumatic brain injury, systemic lupus erythematosus, schizophrenia, intelligence, creativity, and genius. His research has been funded by the National Institutes of Health, The National Endowment for the Arts, DARPA, and the John Templeton Foundation. He is on the Editorial Boards of several journals including: *Intelligence*, *PLoS ONE*, *Frontiers in Neuropsychiatric Imaging and Stimulation*, and the *Creativity Research Journal*.

OSHIN VARTANIAN received his PhD in Psychology from the University of Maine. He is a Defence Scientist at Defence Research and Development Canada, and an Adjunct Assistant Professor in the Department of Psychology at the University of Toronto. He is the co-editor of *Neuroaesthetics* (Baywood), *Neuroscience of Decision Making* (Routledge), and *Neuroscience of Creativity* (The MIT Press). He is the Editor of *Empirical Studies of the Arts*, and serves on the editorial boards of *Creativity Research Journal*, *Thinking Skills and Creativity*, and *Psychology of Aesthetics*, *Creativity, and the Arts*. He is the recipient of the Daniel E. Berlyne Award from Division 10 of the American Psychological Association for outstanding research by a junior scholar for his work on the neuroscience of creativity and aesthetics.



# The Cambridge Handbook of the Neuroscience of Creativity

Edited by
Rex E. Jung
University of New Mexico

Oshin Vartanian
University of Toronto





**CAMBRIDGE**UNIVERSITY PRESS

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

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, 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/9781107147614

DOI: 10.1017/9781316556238

© Rex E. Jung and Oshin Vartanian 2018

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2018

Printed in the United States of America by Sheridan Books, Inc.

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

Library of Congress Cataloging-in-Publication Data

Names: Jung, Rex E. (Rex Eugene), editor. | Vartanian, Oshin, 1970- editor.

Title: The Cambridge handbook of the neuroscience of creativity /

edited by Rex E. Jung, University of New Mexico, Oshin Vartanian, University of Toronto.

Other titles: Handbook of the neuroscience of creativity Description: Cambridge : Cambridge University Press, 2018. |

Includes bibliographical references.

Identifiers: LCCN 2017034636 | ISBN 9781107147614 (hardback) Subjects: LCSH: Cognitive neuroscience. | Creative ability.

Classification: LCC QP360.5 .C3535 2018 | DDC 612.8/233–dc23

LC record available at https://lccn.loc.gov/2017034636

ISBN 978-1-107-14761-4 Hardback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.



## Contents

	List of Figures	page viii
	List of Tables	xi
	List of Contributors	xii
	Acknowledgments	xiv
	Introduction	1
	REX E. JUNG AND OSHIN VARTANIAN	
	Part I Fundamental Concepts	
1	Creative Ideas and the Creative Process: Good News and Bad News for the Neuroscience of Creativity  DEAN KEITH SIMONTON	9
2	Homeostasis and the Control of Creative Drive ALICE W. FLAHERTY	19
3	Laterality and Creativity: A False Trail?  MICHAEL C. CORBALLIS	50
4	The Neural Basis and Evolution of Divergent and Convergent Thought LIANE GABORA	58
	Part II Pharmacology and Psychopathology	
5	Stress, Pharmacology, and Creativity DAVID Q. BEVERSDORF	73
6	Functional Neuroimaging of Psychedelic Experience: An Overview of Psychological and Neural Effects and their Relevance to Research on Creativity, Daydreaming, and Dreaming KIERAN C. R. FOX, MANESH GIRN, CAMERON C. PARRO, AND KALINA CHRISTOFF	92
7	A Heated Debate: Time to Address the Underpinnings of the Association between Creativity and Psychopathology?  SIMON KYAGA	114
8	Creativity and Psychopathology: A Relationship of Shared Neurocognitive Vulnerabilities SHELLEY H. CARSON	136



More Information

vi	Contents	
	Part III Attention and Imagination	
9	Attention and Creativity DARYA L. ZABELINA	161
10	Internally Directed Attention in Creative Cognition MATHIAS BENEDEK	180
11	The Forest versus the Trees: Creativity, Cognition and Imagination ANNA ABRAHAM	195
12	A Common Mode of Processing Governing Divergent Thinking and Future Imagination REECE P. ROBERTS AND DONNA ROSE ADDIS	211
	Part IV Memory and Language	
13	Going the Extra Creative Mile: The Role of Semantic Distance in Creativity – Theory, Research, and Measurement YOED N. KENETT	233
14	Episodic Memory and Cognitive Control: Contributions to Creative Idea Production  ROGER E. BEATY AND DANIEL L. SCHACTER	249
15	Free Association, Divergent Thinking, and Creativity: Cognitive and Neural Perspectives  TALI R. MARRON AND MIRIAM FAUST	261
16	Figurative Language Comprehension and Laterality in Autism Spectrum Disorder RONIT SABAN-BEZALEL AND NIRA MASHAL	281
	Part V Cognitive Control and Executive Functions	
17	The Costs and Benefits of Cognitive Control for Creativity  EVANGELIA G. CHRYSIKOU	299
18	Creativity and Cognitive Control in the Cognitive and Affective Domains	318
10	Andreas fink, Corinna Perchtold, and Christian Rominger	
19	Associative and Controlled Cognition in Divergent Thinking: Theoretical, Experimental, Neuroimaging Evidence, and New Directions  EMMANUELLE VOLLE	333
	Part VI Reasoning and Intelligence	
20	Creativity in the Distance: The Neurocognition of Semantically Distant Relational Thinking and Reasoning	363



		Contents	vii
21	Network Dynamics Theory of Human Intelligence AKI NIKOLAIDIS AND ARON K. BARBEY		382
22	Training to be Creative: The Interplay between Cognition, Learning, and Motivation  INDRE V. VISKONTAS	Skill	405
23	Intelligence and Creativity from the Neuroscience Perspect	ive	421
	Part VII Individual Differences		
24	The Genetics of Creativity: The Underdog of Behavior General DAVIDE PIFFER	etics?	437
25	Structural Studies of Creativity Measured by Divergent Thir HIKARU TAKEUCHI AND RYUTA KAWASHIMA	nking	451
26	Openness to Experience: Insights from Personality Neuroscoshin Vartanian	ience	464
27	Creativity and the Aging Brain KENNETH M. HEILMAN AND IRA S. FISCHLER		476
	Part VIII Artistic and Aesthetic Processes		
28	The Neuroscience of Musical Creativity DAVID BASHWINER		495
29	Artistic and Aesthetic Production: Progress and Limitations MALINDA J. MCPHERSON AND CHARLES J. LIMB		517
30	Polymathy: The Resurrection of Renaissance Man and the Renaissance Brain CLAUDIA GARCIA-VEGA AND VINCENT WALSH		528
	Index		540

The color plates are between pages 322 and 323



## **Figures**

0.1	Frequency of studies of creativity in the psychological sciences.	page 2
0.2	Frequency of studies on the brain bases of creativity.	3
2.1	Near a factor's ideal value, more can be worse.	21
2.2	Two-axis "ameba" model of motivation.	24
2.3	Simplified model of anatomical pathways involved in creative behavior.	27
2.4	Simplified model of frontotemporal and hemispheric effects on creativity.	30
4.1	Neural-level illustration of context-dependency of creative thought.	60
4.2	(a) In this schematic illustration of a portion of memory, the circles represent	
	neurons, and the orange bars represent properties responded to by particular	
	neurons – in this case, lines of a particular orientation. (b) In this more detailed	
	schematic representation of this portion of memory, each vertex represents a	
	possible property, and each black ring represents a property that actually elicits	
	maximal response from an existing neuron.	61
4.3	As in Figure 4.2, in this schematic illustration of a portion of memory, the circles	
	represent neurons, and the orange bars represent properties responded to by	
	particular neurons – in this case, lines of a particular orientation.	62
4.4	These panels provide a schematic illustration of a portion of memory in the process	
	of inventing a beanbag chair.	63
4.5	(a) A schematic depiction of the concept TIRE in its state of full potentiality, with	
	many potential properties or affordances. (b) Depiction of how, in its conventional	
	context car, the concept TIRE collapses on tire-relevant properties such as "goes	
	on wheel" and "filled with air." (c) Depiction of how, in the unconventional context	
	playground equipment, the concept TIRE collapses on the properties that you could	ļ
	hang it and sit on it, which are essential for conceiving of it as a possible swing.	
	(d) Depiction of how, in an even more unconventional context for this concept,	
	pet needs, it collapses on the property "small animal could sleep in it," which is	
	essential for conceiving of it as a dog bed.	65
5.1	Noradrenergic pathways.	75
5.2	Dopaminergic pathways.	80
6.1	An idealized representation of the phases and stages of psychedelic experience.	99
7.1	Associations between case group psychiatric morbidity and creative professions.	115
7.2	Correlations between divergent thinking (BIS score) scores and thalamic dopamine	
	D2 binding potential.	125
8.1	The shared neurocognitive vulnerability model of creativity and psychopathology.	143
8.2	High IQ and reduced latent inhibition predict creative achievement in eminent	
0.2	achievers and controls.	146
8.3	The mad genius paradox and the shared neurocognitive vulnerability model of	1.40
	creativity and psychopathology.	148



More Information

	List of Figures	ix
0.1	Model of Creativity and Attention (MOCA), presenting relations between questive	
9.1	Model of Creativity and Attention (MOCA), presenting relations between creative achievement, divergent thinking, and attention.	167
9.2	A Pearson correlation between divergent thinking and validity effect (RT on invalid	107
9.2	trials minus RT on valid trials), demonstrating that people with higher divergent	
	thinking scores have more flexible attention $(r(152) =23, p = .004)$ .	168
9.3	Grand averages of the ERPs at Cz.	169
9.4	Partial regression plot depicting partial correlations between divergent thinking	109
<i>7.</i> ₹	(centered) and P50 sensory gating.	170
9.5	(a) Neuropshysiological response to rare and frequent targets on an oddball	170
7.5	paradigm, showing a larger N2 ERP on rare compared to frequent targets,	
	particularly at parietal sites, indicating that more cognitive control is required on	
	rare compared to frequent targets. (b) A Pearson correlation between divergent	
	thinking and N2 difference (rare targets minus frequent targets), demonstrating that	
	people with higher divergent thinking scores upregulate their cognitive control to a	
	larger degree on the rare compared to the frequent targets compared to people with	
	lower divergent thinking scores ( $r(26) = .50$ , $p = .004$ ).	171
9.6	Putative associations between COMT (tied to DA availability in the prefrontal DA	
	pathways) and top-down cognitive control; and DAT (tied to DA availability in	
	striatal pathways) and cognitive flexibility.	172
9.7	A Pearson correlation between creative achievement and congruency effect	
	(RT on incongruent trials minus RT on congruent trials), demonstrating that	
	people with higher real-world creative achievements have more "leaky" attention	
	(r(94) = .22, p < .03).	173
9.8	Partial regression plot depicting partial correlations between creative	
	achievement (centered) and P50 sensory gating.	173
11.1	An informal characterization of the cognition–imagination cycle via semantic	
	memory operations.	203
12.1	(a) Significant positive correlation between flexibility scores on the AUT and	
	the mean number of internal details comprising future events on the AI ( $r = .40$ ,	
	p < .01). (b) Hierarchical linear regressions indicated that while the number of	
	internal details for past events ("memory") predicted the number of internal details	
	comprising imagined past <i>and</i> imagined future events, AUT flexibility scores	• • •
	("divergent thinking") only predicted internal details for imagined <i>future</i> events.	219
12.2	Regions reliably contributing to a latent variable showing correlations between	
	brain activity during future imagination (in both <i>Congruent</i> and <i>Incongruent</i>	222
12.1	conditions) and performance on the AUT (flexibility scores).	222
13.1	First neighbors (directly connected concepts) for the word <i>sunset</i> according	
	to the different approaches to measure semantic distance (frequency-based,	220
16.1	LSA-based, and network-based).	238
16.1	The correlations between ironic comprehension and scores on the HMGT (A)	206
19.1	and the vocabulary test (B) in ASD.  Comparative results of functional imaging studies in healthy subjects (meta-	286
17,1	analysis from Gonen-Yaacovi et al., 2013) and a patient study in frontotemporal	
	dementia patients (de Souza et al., 2010).	336
	activities parteting (ac Douza et al., 2010).	220



X	List of Figures	
19.2	Schematic representation of spontaneous and controlled processing for idea	
17.2	generation.	345
20.1	Frontopolar cortex activity during analogical reasoning.	368
20.2	An illustration of a matrix for the Analogy Finding Matrix task (not a	
	high-fidelity reproduction of the actual matrix used).	373
21.1	This figure represents how intrinsic and extrinsic forces drive the concurrent	
	development of brain networks and cognitive function (Byrge et al., 2014).	383
21.2	This figure summarizes recent work extracting reliable functional networks	
	based on a large-scale meta-analysis of peaks of brain activity for a wide range	
	of motor, perceptual, and cognitive tasks (with permission from Dosenbach	
	et al., 2006; Power & Petersen, 2013).	385
21.3	This figure displays a visual summary of basic network structure (van den	
	Heuvel & Sporns, 2013).	387
21.4	This image represents the brain activity and network contributions to the three	
	cognitive components of cognitive control: start cue, error related, and sustained	
	activity (Power & Petersen, 2013).	389
24.1	Creative achievement model.	442
25.1	Schema of GM, WM, cortical thickness, WM surface, and pial surface.	452
25.2	Schema of associations among DTI measures (FA and MD), anisotropic and	
	isotropic water molecule diffusion, and brain tissue components.	453
25.3	GM correlations with CMDT and subscales.	454
25.4	GM correlation with CMDT and subscales in the axial view.	455
25.5	WM correlation with total scores of CMDT among females in a large sample.	456
25.6	A schema of the models of associations among CMDT, personalities,	
	and MD in the bilateral globus pallidum.	458
26.1	Feist's (2010) functional model of the creative personality.	465



## **Tables**

1.1	Creative and noncreative outcomes according to the three-criteria definition.	page 12
2.1	A first-approximation summary of neurotransmitter effects on motivational	
	factors that play a role in laboratory creativity tests.	25
2.2	Some biological influences on creativity.	30
2.3	Medical disorders perceived as linked to creativity.	32
2.4	Drugs that <i>may</i> have effects on creativity.	36
6.1	Neuroimaging investigations of psychedelic experience.	94
6.2	Overview of the major psychedelic substances.	96
6.3	Phases and stages of psychedelic experience.	99
21.1	This table summarizes some of the most important micro- and macro-level	
	graph-theoretical measurements of functional network construction (Bullmore &	
	Bassett, 2011; Bullmore & Sporns, 2009; Rubinov & Sporns, 2009).	387
21.2	This table summarizes the key predictions made by the Network Dynamics	
	Theory of intelligence regarding the role of specific brain networks and	
	development in intelligence	396
24.1	Intraclass correlations for observed variables.	441
24.2	Intraclass correlations for latent personality factors.	441
24.3	Additive genetic (A), shared (C), and nonshared (E) contributions to individual	
	differences in creative cognition and personality.	443
28.1	Structural and functional imaging studies of musical creativity (sMRI, fMRI,	
	PET, EEG).	498
28.2	EEG power/coherence and genetic studies of musical creativity.	502



### Contributors

ANNA ABRAHAM Leeds Beckett University, UK DONNA ROSE ADDIS The University of Auckland, New Zealand ARON K. BARBEY University of Illinois at Urbana Champaign, USA DAVID BASHWINER University of New Mexico, USA ROGER E. BEATY Harvard University, USA MATHIAS BENEDEK University of Graz, Austria DAVID Q. BEVERSDORF University of Missouri, USA SHELLEY H. CARSON Harvard University, USA KALINA CHRISTOFF University of British Columbia, Canada EVANGELIA G. CHRYSIKOU Drexel University, USA MICHAEL C. CORBALLIS University of Auckland, New Zealand MIRIAM FAUST Bar Ilan University, Israel ANDREAS FINK University of Graz, Austria IRA S. FISCHLER University of Florida, USA ALICE W. FLAHERTY Harvard Medical School, USA KIERAN C. R. FOX Stanford University, USA LIANE GABORA University of British Columbia, Canada CLAUDIA GARCIA-VEGA University College London, UK MANESH GIRN University of British Columbia, Canada ADAM GREEN Georgetown University, USA KENNETH M. HEILMAN University of Florida, USA EMANUEL JAUK University of Graz, Austria REX E. JUNG University of New Mexico, USA RYUTA KAWASHIMA Tohoku University, Japan YOED N. KENETT University of Pennsylvania, USA SIMON KYAGA Karolinska Institutet, Sweden



**List of Contributors** 

xiii

CHARLES J. LIMB University of California San Francisco, USA TALI R. MARRON Bar Ilan University, Israel NIRA MASHAL Bar Ilan University, Israel MALINDA J. MCPHERSON Harvard University, USA AKI NIKOLAIDIS The Child Mind Institute, USA CAMERON C. PARRO University of British Columbia, Canada CORINNA PERCHTOLD University of Graz, Austria DAVIDE PIFFER Ulster Institute for Social Research, UK REECE P. ROBERTS The University of Auckland, New Zealand CHRISTIAN ROMINGER University of Graz, Austria RONIT SABAN-BEZALEL Bar Ilan University, Israel DANIEL L. SCHACTER Harvard University, USA DEAN KEITH SIMONTON University of California Davis, USA HIKARU TAKEUCHI Tohoku University, Japan OSHIN VARTANIAN University of Toronto, Canada INDRE V. VISKONTAS University of San Francisco, USA EMMANUELLE VOLLE Sorbonne Universités, France VINCENT WALSH University College London, UK

DARYA L. ZABELINA University of Arkansas, USA



## Acknowledgments

#### **REJ**

There are two people who have provided me great support in my personal and professional life: my wife, Ann without whom I would be lost, and my colleague Rich Haier, without whom I would be adrift. Thank you both for making me a better man, friend, and scientist.

This work would not be possible without the support of the John Templeton Foundation, who found promise in a crazy researcher who wanted to explore where the neuroscience of creativity would take him. We have done well together. Thank you.

Finally, I want to thank Oshin Vartanian, who contrasted all of my (dis)agreeable personality characteristics with equanimity, patience, and kindness. You have been a good partner, and I thank you for your willingness to associate with such a trying character.

#### OV

I would like to thank my parents, Albert and Knarik Vartanian, and my family, Alexandra, Atam and Aren for their love and support.

I am truly grateful to Rex Jung for considering me as his companion on this wonderful journey. The pleasure of working together has been all mine.

Finally, I am forever indebted to Colin Martindale, whom I consider to be the patron saint of the neuroscience of creativity. Thank you for opening the door to the garden.