

Spatial Working Memory

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*Professor of Human Cognitive Neuroscience,
University of Edinburgh, UK*

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Spatial Working Memory

**Edited by André Vandierendonck &
Arnaud Szmalec**



Psychology Press
Taylor & Francis Group
HOVE AND NEW YORK

First published 2011
by Psychology Press
27 Church Road, Hove, East Sussex BN3 2FA

Simultaneously published in the USA and Canada
by Psychology Press
711 Third Avenue, New York NY 10017

www.psypress.com

Psychology Press is an imprint of the Taylor & Francis Group, an informa business

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British Library Cataloguing in Publication Data

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

Typeset in Times by
Refine Catch Limited, Bungay, Suffolk
Cover design by Lisa Dynan

[FSC logo dropped in by printer] [Printer info - dropped in by printer]

Library of Congress Cataloging-in-Publication Data

Spatial working memory / edited by André Vandierendonck & Arnaud Szmałec.

p. cm.

Includes bibliographical references and index.

ISBN 978-1-84872-033-6 (hb)

1. Short-term memory. 2. Space perception. I. Vandierendonck, André. II. Szmałec, Arnaud.

BF378.S54S63 2011

153.1'3—dc22

2010053316

Contents

<i>List of contributors</i>	vi
<i>Preface</i>	vii
1 Progress in spatial working memory research	1
ANDRÉ VANDIERENDONCK AND ARNAUD SZMALEC	
2 The visual and the spatial of a multicomponent working memory	19
ROBERT H. LOGIE	
3 Spatial information in (visual) working memory	46
HUBERT D. ZIMMER & HEINRICH RENÉ LIESEFELD	
4 Exploring the determinants of memory for spatial sequences	67
FABRICE B. R. PARMENTIER	
5 What underlies the ability to guide action with spatial information that is no longer present in the environment?	87
BRADLEY R. POSTLE	
6 The organization of visuospatial working memory: Evidence from the study of developmental disorders	102
CESARE CORNOLDI AND IRENE C. MAMMARELLA	
7 The nature of visuospatial representation within working memory	122
COLIN HAMILTON	
8 What can symmetry tell us about working memory?	145
LAURA PIERONI, CLELIA ROSSI-ARNAUD, AND ALAN BADDELEY	
9 The role of spatial working memory in understanding verbal descriptions: A window onto the interaction between verbal and spatial processing	159
VALÉRIE GYSELINCK AND CHIARA MENEGHETTI	
<i>Author index</i>	00
<i>Subject index</i>	00

Contributors

Alan D. Baddeley is in the Department of Psychology at the University of York, UK.

Cesare Cornoldi is in the Department of General Psychology at the University of Padua, Padova, Italy.

Valérie Gyselinck is in the Department of Psychology and Cognitive Neurosciences at CNRS Université de Paris, France.

Colin Hamilton is in the Department of Psychology at Northumbria University, Newcastle upon Tyne, UK.

Heinrich René Liesefeld is in the Department of Psychology, the Brain & Cognition Unit at Saarland University, Saarbrücken, Germany.

Robert H. Logie is in the Department of Psychology at the University of Edinburgh, UK.

Irene Mammarella is in the Department of Developmental Psychology at the University of Padua, Padova, Italy.

Chiara Meneghetti is in the Department of General Psychology at the University of Padua, Padova, Italy.

Fabrice B. R. Parmentier is in the Department of Psychology at the University of the Balearic Islands, Palma, Spain.

Laura Pieroni is in the Dipartimento di Psicologia at Sapienza Università di Roma, Italy.

Bradley R. Postle is in the Cognitive Neuroscience Laboratory, Departments of Psychology and Psychiatry at the University of Wisconsin, Madison, USA.

Clelia Rossi-Arnaud is in the Dipartimento di Psicologia at Sapienza Università di Roma, Rome, Italy.

Arnaud Szmalec is in the Department of Experimental Psychology at Ghent University, Belgium.

André Vandierendonck is in the Department of Experimental Psychology at Ghent University, Belgium.

Hubert D. Zimmer is in the Department of Psychology, the Brain & Cognition Unit at the Saarland University, Saarbrücken, Germany.

Preface

The idea for this book arose during an international psychology conference that took place in 2008 in Berlin. During the course of the conference one of us (A.V.) enjoyed a drink in the sunshine with Robert Logie. The discussion wandered over many ideas and topics and came to that of working memory. It resulted in us agreeing that the pace of recent evolutions in research on visual and spatial working memory warranted a book taking stock of the current situation. It was not clear at that stage how broad the focus of the book was going to be. However, 6 weeks later, at the fourth European Working Memory Symposium (EWOMS-4) the idea was discussed further with several colleagues attending this small conference in rainy Bristol and this led to the decision that we would invite colleagues to contribute a chapter on *spatial working memory*, as distinct from *visual* working memory and visual object memory. This book is about how we are able to remember at which place in space something was perceived and how we are able to recall in which order we visited a series of locations.

Although the capacity to remember spatial information is biologically of utmost importance, in our modern society, this ability is completely overpowered by the verbal world, as if something that cannot be expressed verbally has no reason for existence and is possibly not in our minds. This verbal dominance has for a long time governed research on all kinds of memory, and still continues to do so. Whereas most publications address verbal memory, only a small minority are devoted to visual and/or spatial processes. This verbal dominance existed when Alan Baddeley and Graham Hitch (1974) first formulated their ideas about working memory: a short-term information storage system that also allows operations on the stored information. In their conception of working memory, dedicated modality-specific storage systems were included for verbal (phonologically coded) information and for visual and spatial information. After an initial strong research focus on verbal working memory, which continues even today, visual and spatial working memory appeared more and more in the picture. While in the last two or three decades, the amount of research on working memory has expanded, the number of publications on visual and spatial working memory has also tremendously increased in an attempt to catch up with the verbal tradition. The trends observable in the web of science are ostensibly clear on this. In the 1980s only 26 articles were published on the topic of spatial working memory; in the 1990s this increased to 551, and in the first decade of the twenty-first century, 2291

articles appeared. In other words, in the last decade, four times as many articles addressed spatial working memory compared with two decades before. However, the trend in working memory research in general, has expanded similarly. Nevertheless, in view of this strong growth of research regarding spatial working memory, a book like the present one can help readers find their way through the vast number of findings and theories.

The book tries to achieve this goal by providing a forum for top researchers in the domain of spatial working memory to review and discuss findings in relation to their own views and the hypotheses of colleagues about the processes and the memory structures underlying the ability to store and to operate on spatial information. Our general idea is that spatial working memory concerns the storage and manipulation of information that refers to locations in space irrespective of the modality of the receptors (visual, auditory, kinesthetic, etc.) that provided the information. The core characteristic of spatial information is location in space; it can be specified in an egocentric or an allocentric frame of reference. In an egocentric reference, a location is expressed in relation to the perceiver, whereas an allocentric reference specifies a location in relation to environmental features or to other objects in space, independently from the position of the perceiver. In some situations, one type of reference must be translated into the other type, the most extreme example of which is a translation from a verbal description to a spatial layout.

A thread throughout the volume concerns the specification of the kind of system that allows spatial working memory abilities. Is working memory a modality-free system for temporary maintenance that can operate on different kinds of memory content, or is it composed of several functionally separable systems that are each dedicated to one particular input modality? In a similar vein, are there specializations for processing simultaneous and sequential information, or is the working memory system a general purpose system that can cope with dynamic as well as static information. How does the system bind information from different modalities into a unitary representation? Broadly, the book consists of two parts. Chapters 1–5 deal with the question of what kind of system working memory is. On the basis of available data, these chapters elucidate behavioural limitations and regularities of working with (visuo)spatial information and how these constrain our hypotheses of the working memory system. Part of this problem concerns the basic architecture of the working memory system and its specialized subsystems. These chapters also address methodological questions, such as how the research method can ensure that the observed data are informative about underlying structures. In the second part, Chapters 6–9 do not ignore these theoretical background issues but rather focus on specific problems of spatial working memory, such as how our views on working memory can be used to better understand the development of particular skills in children with developmental deficiencies, or how the working memory system can handle individual differences in the representation of spatial information, or how the visuospatial system can support and interact with the environment or with the verbal system.

In the first chapter, ‘Progress in spatial working memory research’, André Vandierendonck and Arnaud Szmalec focus on the theoretical question of which

kind of architecture is needed to explain the extant data on spatial working memory. The multicomponent view of working memory is the oldest one and was for a long time the only available view. More recently, other researchers have proposed models in which long-term memory receives a prominent place. Inevitably, the question arises of which kind of architecture is the best one to summarize the existing data and is the most productive one to generate new predictions. In this context, the authors focus on a series of findings regarding the representation of spatial order. They also discuss the utility of the interference and dissociation methodology that is typically used to distinguish between subsystems of the proposed working memory architectures.

In Chapter 2, 'The visual and the spatial of a multicomponent working memory', Robert H. Logie reviews the vast amount of evidence in support of the multicomponent working memory architecture. This review reveals support for dissociable storage systems for verbal/phonological information on the one hand and visuospatial information on the other. Moreover, visual and spatial storage are also shown to be dissociable, and at the same time, the author shows that these two systems have a common basis. This review also addresses dissociations between domain-specific (verbal, visual, spatial, ...) and domain-general process (the central executive in the multicomponent model). It is stressed how all these components work together in specific tasks and situations. A consequence of this is that it is important to carefully apply the dissociation methodology in order to ensure that a particular task setting is not achieved by other working memory components than the ones intended.

Hubert D. Zimmer and Heinrich René Liesefeld expand on the representation of 'Spatial information in (visual) working memory' in the third chapter. These authors also adhere to a multicomponent view of working memory. Based on a distinction between different types of tasks, these authors discuss the role of eye movements and of covert attention shifts as spatial rehearsal mechanisms, and the role of sequential and visual information in tasks that require remembering the order of a sequence of locations or positions. They go on to discuss the role of spatial information in tasks where visual distinctions between objects are possible and how several underlying processes (visual, spatial, executive, ...) may each contribute to different tasks.

In Chapter 4, 'Exploring the determinants of memory for spatial sequences', Fabrice B. R. Parmentier reviews the literature regarding the support for modality-specific specializations within working memory. The review shows that there is an impressive amount of evidence in favour of separate storage systems for verbal and visuospatial information. The review also shows, however, that specifically when memory for sequence order is involved, many studies failed to find modality-based dissociations and, on the contrary, showed cross-modal interference. The author explores the consequences of these findings for our views on working memory, in particular, spatial working memory.

Although all these chapters (1–4) focus on behavioural studies, occasionally they refer to patient data or to data that have been obtained using neurophysiological methods. Nevertheless, neuroscience-based approaches (e.g., event-related potentials, functional magnetic resonance imaging, transcranial magnetic

stimulations, etc.) are very informative with respect to brain regions and brain pathways involved in all kinds of cognitive tasks. Chapter 5 by Bradley R. Postle addresses these issues under the title ‘What underlies the ability to guide action with spatial information that is no longer present in the environment?’. The author reviews a selection of studies that address working memory for spatial information and shows how working memory systems can be specified as emergent properties of particular processing stages.

In Chapter 6, ‘The organization of visuospatial working memory: evidence from the study of developmental disorders’, Cesare Cornoldi and Irene Mammarella explore cases in which the functioning of spatial working memory is deficient or suboptimal. On the one hand, the existing knowledge and models of working memory can be used to better understand cases of impaired cognitive development; on the other hand, information obtained in the study of children with developmental dysfunction also provides constraints on theory development. In addition to a review of relevant evidence, these authors discuss in more depth the characteristics of spatial working memory in children with Down syndrome, Williams syndrome, spina bifida, and children with nonverbal learning deficiencies.

Chapter 7, ‘The nature of visuospatial representation within working memory’, by Colin Hamilton provides an extensive review of the popular spatial and visual task protocols. It is argued that a clear separation between visual and spatial working memory processing is difficult to operationalize. The author goes on to summarize evidence for a multicomponent view on spatial and visual working memory from experimental research and individual differences within both a neuropsychological and developmental context, including some of the author’s own work. The chapter ends with an attempt to integrate the reviewed findings in Baddeley’s (2000) working memory model and Cornoldi and Vecchi’s (2003) continuity model, while remaining open to alternative (e.g., single resource) views and discussing ways to proceed in future research.

In Chapter 8, ‘What can symmetry tell us about working memory?’, Laura Pieroni, Clelia Rossi-Arnaud and Alan Baddeley explore the role of environmental properties such as pattern and path symmetries. Research has shown that all kinds of similarities and redundancies in a to-be-memorized stimulus affect memory performance. Regularities in memory performance based on similarities or dissimilarities are very informative about the underlying structure. For example, the observation that phonological similarities in visually presented words affect short-term memory recall was at the basis of the hypothesis that verbal short-term memory strongly relies on phonological codes. Similarly, within the visuospatial modality, stimulus similarity and stimulus structure have been found to play an important role. One of these is symmetry, not only within a set of simultaneously presented elements that constitute an object or a shape, but also in sequentially presented elements at different locations, the symmetry in a spatial sequential path affects memory performance. Interestingly, only vertical symmetry seems to be relevant in spatial paths and the question is why this, and only this, kind of symmetry affects performance. What can this specific finding tell us about the underlying working memory mechanisms?

The final chapter, ‘The role of spatial working memory in understanding verbal descriptions: a window onto the interaction between verbal and spatial processing’, addresses the interaction of spatial and verbal working memory. Valérie Gyselinck and Chiara Meneghetti review a range of studies in which the main question is how verbal descriptions of spatial organizations, such as a route through a city, a description of a spatial layout or situation are handled by the working memory system. They review an accumulation of evidence showing that this kind of verbal information is preferentially stored and operated on by means of visual and spatial codes. This work shows that the human working memory system is refined, specialized, and flexible. The chapter also shows how working memory intertwines with all kinds of cognitive processes and skills and in that respect it takes on the role of a concluding and overarching chapter.

The present volume presents a representative but not an exhaustive review of the literature on spatial working memory. We hope the book is of value to all researchers working on cognitive skills in relation to spatial representations and working memory more generally. We also believe the book is useful for students interested in spatial working memory in that it provides a short route to the literature. Finally, we hope that many other readers find in this book an interesting overview of the state of the art regarding working memory for spatial information, which will provoke some debate and thus stimulate further development in (spatial) working memory theory.

In closing, we would like to thank everyone who helped us in the different stages of the realization of this book.

André Vandierendonck
Arnaud Szmalec
Ghent, 30 June 2010

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