INTRODUCTION

Po says: you will find what you have lost but first you must remember where you have left it.

(Reading from a fortune cookie at a Chinese restaurant somewhere in the deep southwest)

SPACE IS SPECIAL

Our lives very much depend on our ability to perceive, remember, and act upon where things are in the world. From finding the things you want to buy in the supermarket, to packing them in your car; from recalling the way to your hotel during a weekend trip, to navigating the newest update of your computer's operating system; from combing your hair in the mirror, to solving a geometric problem during a university exam; each challenge requires some form of mental handling of spatial information.

Dealing with everyday life's spatial assignments may not always run very smoothly. One of us (Albert Postma) conducted a study some years ago in which he asked visitors to a shopping mall if they ever encountered problems in remembering where they parked their car (Postma, van Oers, Back, & Plukaard, 2012). Close to 50% of the interviewed participants reported occasional to regular difficulties. When tested more objectively on their efficiency to find their car back after the actual shopping mall visit, 15% of the participants made a considerable detour. Though annoying, these problems usually do not have a huge impact on our lives. We can typically find the desired object after some effort. In turn, we can collect additional cues such as road signs and names, in order to find the way when running the danger of getting lost. In contrast, various forms of brain damage do have a really profound effect on spatial orientation, memory, and reasoning. The central theme of this book is what happens to spatial cognitive functions after either global or local disturbances of the central nervous system. Importantly we intend not just to sketch the clinical profile for a given spatial disorder. We also try to give broader cognitive, neurocognitive, and applied perspectives. As such we use the described cases and groups of patients as models for further understanding of the (spatial) cognitive domain at stake. We will discuss how specific neuropsychological disorders inspire and can be used to modify relevant

theoretical frameworks, and reversely, how theoretical frameworks can be used to better understand neuropsychological impairments. Both work with patient groups and exemplary cases will be featured. This can offer invaluable neurocognitive insights. Moreover, it will also illustrate methodological issues of neuropsychology at large (ie, the ins and outs of single case methodology, lesion overlap approaches in patient groups). Finally, we intend to also include an applied perspective: how does spatial cognition operate in the real world; what is the ecological validity of certain tasks; which daily life problems do neuropsychological patients encounter in certain domains; which rehabilitation possibilities for spatial functions exist; what is the potential of new techniques (virtual reality; GPS tracking) to support spatial cognition?

ON THE HISTORY OF SPACE (AT LEAST OF THE CURRENT BOOK ON SPACE)

The origins for this book go back to the first years of the 21st century when one of us (Albert Postma) started a research program on spatial cognition at Utrecht University, focusing on a variety of spatial functions, supported by a grant from the Dutch science foundation (NWO). He later was joined by Ineke van der Ham who completed her PhD thesis on the hemispheric lateralization of spatial functions within that program and stayed on as an assistant professor. From 1999 on we have been coordinating and giving lectures in the honours Bachelor course Spatial Cognition, University College Utrecht. A central idea in these lecture series as well as in the accompanying research program has been that spatial information processing is intrinsic to all cognitive domains: perception, attention, motor action, memory and representation, reasoning, and communication. This book intends to do justice to this idea and therefore entails a varied functional approach to the spatial cognition. We will trace space across the cognitive domains, and where possible try to highlight interconnections. Of course, throughout the chapters the special place of spatial cognition within neuropsychological research will be highlighted.

A MAP OF THE BOOK

In Chapter 1, A Sense of Space, Albert Postma and Jan Koenderink sketch an example from daily life that serves to set the floor for several conceptual questions that will be returned to later in that chapter. In particular it illustrates how different cognitive domains encompass a spatial

element. A foremost question addressed in Chapter 1, A Sense of Space, concerns what is space and how do we measure it? This question has been at the center of many philosophical debates throughout the centuries. Some are briefly addressed here: is space absolute or relative; is it real or ideal; is the sense of space innate or does it have to be learned by an accumulation of experiences? This last debate returns in Chapter 9, How Children Learn to Discover Their Environment: An Embodied Dynamic Systems Perspective on the Development of Spatial Cognition, in which the development of spatial cognition is further addressed. Regarding the measurement of space the notion of reference frames is essential: we need to determine places, directions, and relations always with respect to some reference object or frame. Mentally we appear to be able to choose from a large repertoire of references frames, depending on the task at hand. Postma and Koenderink in Chapter 1, A Sense of Space, present a noninclusive overview of possible reference frames and related task domains.

One of the main channels through which we interact with space is our visual system. In Chapter 2, On Inter- and Intrahemispheric Differences in Visuospatial Perception, Ineke van der Ham and Francesco Ruotolo discuss the spatial features of visual perception. In the first part of this chapter they address a prominent dichotomy within visuospatial perception, that of categorical and coordinate spatial relations. We can perceive specific spatial situations in terms of categories (eg, "left of," "above") or metric properties (distances between elements), which are strongly linked to our left or right hemisphere, respectively. Reference frames also return in this chapter, as another important dichotomy within this domain. In particular, the distinction between egocentric and allocentric frames of reference is described. This distinction as well has a solid foundation in dissociated neural correlates.

Touch is particularly relevant to space very near to our bodies, peripersonal and/or body space, a topic thoroughly discussed in Chapter 3, On Feeling and Reaching: Touch, Action and Body Space. Chris Dijkerman shares his thoughts on peripersonal space, a prominent topic within neuropsychology. In addition to patient studies, also experiments are presented in which bodily illusions are induced in healthy participants. Peripersonal space is not just there for processing touch. It also constitutes a primary control center over spatiomotor actions. Many patient studies were consulted in the theoretical framing of the functions of the ventral and the dorsal stream and how they are involved in perception versus action.

In Chapter 4, Multisensory Perception and the Coding of Space, Nathan van der Stoep, Tanja Nijboer, and Albert Postma show that it is

relevant to study spatial senses not only in isolation, such as within vision (see chapter: On Inter- and Intrahemispheric Differences in Visuospatial Perception) or touch (see chapter: On Feeling and Reaching: Touch, Action, and Body Space), but also in combination with one another. Apart from vision and touch, audition also provides us with vital spatial information, typically in combination with one of the other spatial senses. Special focus is given to the mechanisms of multisensory integration and how multisensory stimulation may help reduce or overcome some of the spatial impairments caused by cerebral brain damage. van der Stoep and colleagues also elaborate on what happens when one loses a sense completely. A closer look is taken at the effects of either visual or auditory deprivation on spatial cognition. The complexities of integrating different senses are all the more clear in the case of deafness or blindness.

Being able to perceive spatial information is only a first step, we also have to attend to it, in order to act on it. In Chapter 5, Spatial Attention and Eye Movements, Stefan Van der Stigchel and Tanja Nijboer therefore discuss the domain of spatial attention. In particular, eye movements allow for examination of spatial attention and are therefore the key variable in many spatial attention experiments. One of the landmark disorders of spatial cognition in the past century has been spatial neglect: patients who are completely unresponsive toward one side of space. This is typically explained in terms of spatial attentional failure. In Chapter 5, Spatial Attention and Eye Movements, the authors present a daring new theory on spatial neglect: a deficit in spatial remapping.

Once perceived and attended to, we can process spatial information in many different ways. One of the most prominent ways to do this is by spatial language. Marijn Struiksma and Albert Postma discuss this topic in Chapter 6, Tell Me Where to Go: On the Language of Space. We communicate about space, using spatial language at various scales: explaining a route to a tourist ("take a left turn here," "go north for three blocks"), and also telling your friend where to find the car keys ("on the kitchen table"). In this chapter the authors discuss how different sources of information are used to build representations of space, and what linguistic processes can tell us about these representations. Remarkably, reference frames appear to play a role not just in perception and memory but also in language understanding. Effective communication critically depends on choosing the appropriate reference frame.

A different way to process perceived and attended spatial input is to encode it into memory. Albert Postma and Ineke van der Ham elaborate

on spatial memory in Chapter 7, Keeping Track of Where Things Are in Space: The Neuropsychology of Object Location Memory. A discussion of general memory theory highlights the importance of spatial information in working memory. Many of the spatial memory studies, some of which performed at Utrecht University, have focused on object location memory in particular. This memory has the distinct elements of memorizing object identities, object locations (which can be either categorical or coordinate, as discussed in chapter: On Inter- and Intrahemispheric Differences in Visuospatial Perception), and the connection between objects and their positions. Experimental studies in both healthy and brain-damaged patients have contributed to these findings.

In Chapter 8, Navigation Ability, Ineke van der Ham and Michiel Claessen go from more static spatial memory to dynamic spatial memory. Navigation includes interaction with space at a much larger scale: the process of finding your way around in the world. In the first part of this chapter they discuss the leading theoretical issues concerning navigation ability. Again, reference frames, or "perspective taking" are highly relevant here. The second part concerns the clinical perspective on navigation ability: a significant proportion of neuropsychological patients have specific complaints with regard to navigation. Yet, standardized diagnostic and treatment tools are currently lacking. The authors provide suggestions on how experimental and clinical findings can be used to work on the development of these much-needed tools.

The topics discussed in this book concern human cognition in general, but in Chapter 9, How Children Learn to Discover Their Environment: An Embodied Dynamic Systems Perspective on the Development of Spatial Cognition, Hanna Mulder, Ora Oudgenoeg-Paz, Annika Hellendoorn, and Marian Jongmans provide an overview of spatial cognition from a developmental perspective. In this chapter, embodiment, spatial memory, orientation, and navigation are discussed with a specific focus on children. In particular, the authors pay attention to experimental characteristics of task that are used to examine these domains for young children, and what methodological issues should be kept in mind. The overview offered in Chapter 9, How Children Learn to Discover Their Environment: An Embodied Dynamic Systems Perspective on the Development of Spatial Cognition, certainly also bears on the philosophical debate briefly addressed in Chapter 1, A Sense of Space, on the innateness of our spatial ability.

As this book is centered on neuropsychology, the final chapter concerns a discussion of how spatial cognition finds its place in clinical neuropsychology. In Chapter 10, Space in Neuropsychological Practice, Esther van den Berg and Carla Ruis, discuss case studies with specific spatial impairments and describe how such impairments are typically dealt with in clinical practice. A variety of standardized tests concerning spatial abilities is available, but technological advances such as virtual reality and other digital aids can be very helpful. The authors provide recommendations for both testing and treating spatial problems.

SPACE, THE FINAL FRONTIER: CONCLUDING THOUGHTS

There is a growing need to place the spatial functions of the brain within a broader context: philosophical, neuroscientific, comparative, geographical, cognitive psychological, and neuropsychological. We realize we have not done justice to all of these fields. We have chosen the clinical approach as a leading theme but always in combination with a cognitive and neurocognitive emphasis. We hope the book will be of interest to both researchers and clinicians with an interest in the human cognitive functioning in the spatial domain, from a broad range of backgrounds. We may finish here with a final thought on where exactly is spatial cognition in the human brain. This book shows that the human brain is capable of a wide repertoire of spatial mental operations and entails a large, dedicated neural circuitry underlying these operations. It is too simple to say that this circuitry is only found in the right side of the brain. Also the left hemisphere supports cognitive operations, which we could label as spatial in a broad sense. Given its versatility and relevance for everyday functioning as well as survival in general, the conclusion could be "spatial cognition is all over the brain." After finishing this book this only seems logical.

Albert Postma and Ineke J.M. van der Ham

Utrecht, April 1, 2016

REFERENCE

Postma, A., van Oers, M., Back, F., & Plukaard, S. (2012). Losing your car in the parking lot: Spatial memory in the real world. *Applied Cognitive Psychology, 26*(5), 680–686. Available from http://dx.doi.org/10.1002/acp.2844.