COGNITION

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Cognition 79 (2001) 263–299

www.elsevier.com/locate/cognit

Language, space, and the development of cognitive flexibility in humans: the case of two spatial memory tasks[☆]

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Received 10 February 2000; received in revised form 5 June 2000; accepted 23 September 2000

Abstract

Prior experiments have shown that young children, like adult rats, rely mainly on information about the macroscopic shape of the environment to reorient themselves, whereas human adults rely more flexibly on combinations of spatial and non-spatial landmark information. Adult rats have also been shown to exhibit a striking limitation in another spatial memory task, movable object search, again a limitation not shown by human adults. The present experiments explored the developmental change in humans leading to more flexible, human adult-like performance on these two tasks. Experiment 1 identified the age range of 5–7 years as the time the developmental change for reorientation occurs. Experiment 2 employed a multiple regression approach to determine that among several candidate measures, only a specific language production measure, the production of phrases specifying exactly the information needed to solve the task like adults, correlated with the reorientation performance of children in this age range. Experiment 3 revealed that similar language production abilities were associated with more flexible moving object search task performance. These results, in combination with findings with human adults, suggest that language production skills play a causal role in allowing older humans to construct novel representations rapidly, which can then be used to transcend the limits of phylogenetically older cognitive processes. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Language; Space; Cognitive flexibility; Humans; Spatial memory tasks

☆ The experiments described in this article have been reported previously at conferences in poster form (Hermer, 1994, 1998) and in a published dissertation (Hermer, 1997a).

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PII: S0010-0277(00)00120-7

1. Introduction

Over the course of the 100 000–150 000 year history of our species, *Homo sapiens sapiens*, the knowledge possessed by individuals and cultures has exploded. Faint beginnings of art and religion appear in tombs and artifacts from Africa 90 000 years ago (Holden, 1998). Within a few tens of thousands of years, cave art, sculpture, stone and metal work, and many varieties of tool use flourished (Appenzeller, 1998). Shortly before the onset of the Agricultural Revolution about 10 000 years ago, group size and cultural organization expanded greatly (Balter, 1998), and in the last 200 years alone we have undergone the Industrial and Information Revolutions. In so doing, humans have defined and solved many novel problems for which biology had not explicitly prepared us, such as inventing the wheel, the internal combustion engine and the computer, and creating the Internet. What cognitive capacities gave us the flexibility to invent these technologies and master the systems of knowledge that underpin them?

Assuming that cognition follows general principles of biological evolution, biology offers some guidance as to how to think about these special cognitive mechanisms. In general, there is tremendous conservation of biological processes, and phylogenetically newer mechanisms often are layered on top of older ones (Ridley, 1993). For example, most cells evolved the ability to perform cellular respiration once oxygen became abundant in the environment, but virtually all living cells still also perform glycolysis, the ancient energy extraction solution (Alberts et al., 1992). Moreover, recent innovations often develop later in ontogeny than do older mechanisms, so as not to disrupt older mechanisms and the beneficial ways in which they mesh with other emerging traits (Ridley, 1993). For instance, cartilage appeared in fishes long before bones, and cartilage develops in bony fishes early in life, later replaced by bone (Ridley, 1993).

Evolution that proceeds in this way is called *terminal addition* (Ridley, 1993). Although evolution often progresses in other ways, terminal addition occurs often enough to suggest one logic for studying the emergence of human-specific cognitive traits: find a trait for which young children show the phylogenetically older and more common mechanism but for which human adults show distinctive flexibility, and then study the developmental change in depth. To pursue this goal, it is important to choose a research area about which much is known so that the extension of the core trait by the human-specific trait can be understood in detail.

With these considerations, we focused on the research area of navigation and spatial memory. Since the discovery of putative ‘cognitive maps’ 50 years ago (Tolman, 1948) and the discovery of place cells of the hippocampus 30 years ago (O’Keefe & Dostrovsky, 1971), there has been an explosion of behavioral and neurobiological research in this area. Moreover, Biegler and Morris (1993) and Cheng (1986) reported striking limitations shown in the spatial memory abilities of adult rats, which do not appear to be shown by adult humans. The limitation Cheng discovered concerned a process called *spatial reorientation*. When mammals move about, they normally update their position and heading by *path integration*, using vestibular, motor feedback, and optical flow signals to compute the extent of