Available online at www.sciencedirect.com
ScienceDirect
Cognitive Systems Research 12 (2011) 321–335
Cognitive Systems RESEARCH
www.elsevier.com/locate/cogsys

Checking the ACT-R/Brain Mapping Hypothesis with a complex task: Using fMRI and Bayesian identification in a multi-dimensional strategy space

Action editor: Marco Ragni

Claus Möbus [a], Jan Charles Lenk [a,*], Jale Özyurt [b], Christiane M. Thiel [b], Arno Claassen [a]

[a] *Learning and Cognitive Systems, Department of Computing Science, University of Oldenburg, Germany*
[b] *Biological Psychology Lab, Department of Psychology, University of Oldenburg, Germany*

Received 26 April 2010; received in revised form 24 November 2010; accepted 25 November 2010
Available online 6 January 2011

Abstract

John R. Anderson proposed a correspondence between ACT-R modules and brain regions. In his studies he compared ACT-R-predicted blood-oxygen-level dependent (BOLD) signal curves with BOLD curves obtained from functional Magnetic Resonance Imaging (fMRI) scans. Most of his studies were conducted solving simple algebra tasks. Using different and more complex problems dealing with the interpretation of chemical formulae, we studied the Brain Mapping Hypothesis' robustness towards a different domain, multidimensional strategy spaces, and modeling errors. The ACT-R architecture tolerates various model implementations of the same task with similar behavior but different BOLD predictions. We repeated the analysis for six different models, each implementing a different strategy for the problem with the result that correlations vary between model-generated and empirical BOLD curves according to the selected problem-solving strategy. As an overall result we could not disconfirm Anderson's Brain Mapping Hypothesis, but we could not rule out that ACT-R modules are distributed across more brain regions than Anderson suggested.

Keywords: ACT-R; BOLD prediction; Brain Mapping Hypothesis; Strategy-dependent check of Brain Mapping Hypothesis; Bayesian identification of problem-solving strategies

1. Introduction

The ACT-R architecture by John R. Anderson (Anderson et al., 2004) is one of the most-widespread cognitive architectures. It provides a set of modules with specific functions. Of late, Anderson concentrates on the neurophysiologic analogy and postulates a mapping between these modules and brain regions (Anderson, 2007a, Anderson, Fincham, Qin, & Stocco, 2008b). For instance, the Production module is mapped onto the basal ganglia, while the Declarative module is mapped around the inferior frontal sulcus. The ACT-R 6.0 implementation provides a set of tools which directly predict BOLD signals for these brain regions.

The empirical validation and the robustness of the Brain Mapping Hypothesis is among the research goals of our multidisciplinary research project.[1] While also the effects of affective and informative feedback on learning are being studied (Özyurt, Rietze, & Thiel, 2008, 2010), our accompanying fMRI study offers us the possibility to compare

* Corresponding author.
E-mail address: jan.lenk@uni-oldenburg.de (J.C. Lenk).

[1] *Cognitive Modeling and Bayesian Identification Analysis* (CoMBIAn), work package within project *Impact of affective and informative feedback on learning in children before and after a reattribution training: An integrated approach using neuroimaging, educational research and modeling*, Möbus, Moschner, Parchmann & Thiel (main applicant), BMBF-Program for the Promotion of Scientific Collaboration between the Neurosciences and Research on Learning and Instruction, 06/01/2008-05/31/2011.

1389-0417/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.cogsys.2011.01.001

BOLD signal predictions generated from strategy-specific ACT-R models with BOLD signals obtained from actual fMRI scans. However, the difficulties we encountered during our efforts suggested a refinement of our modeling methods. In contrast to the experiments described by Anderson et al. (Danker & Anderson, 2007), the tasks in our experimental setting allowed the participants to choose their *personal* strategies. Because different strategies lead to different brain region activation predictions, we had to model these different strategies and identify the chosen subject-specific strategy (Möbus et al., 2009) *without* using fMRI data (Fig. 1). We would work unduly in favor of the mapping hypothesis if we assigned subjects to strategies according to similarity of their BOLD curves with the strategy-specific ACT-R–BOLD curves.

1.1. Brain Mapping Hypothesis

The ACT-R architecture consists of different modules which perform specific functions during cognitive processes. The Visual and Aural modules perform perceptual functions while the Vocal and Manual modules effect concrete actions such as typing on a keyboard or utterances. The Declarative and Imaginal modules implement long

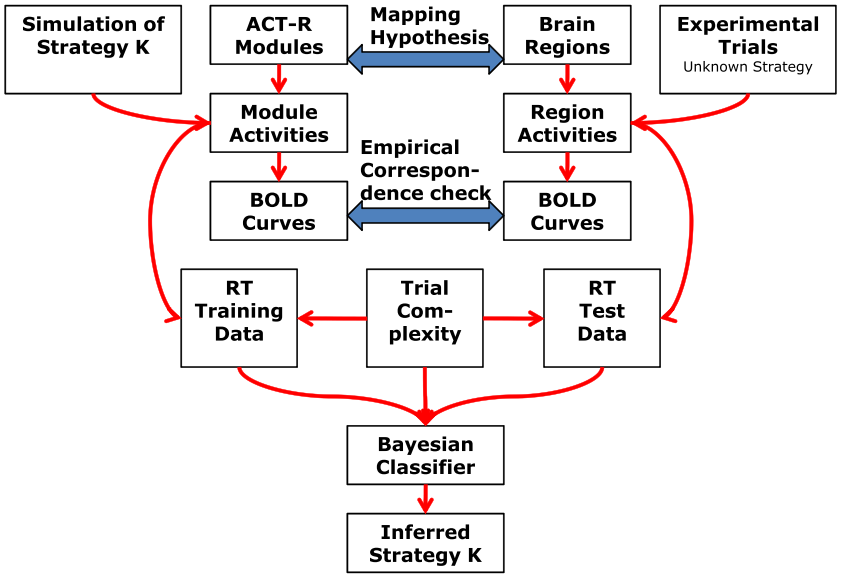

Fig. 1. Process model for strategy classification.

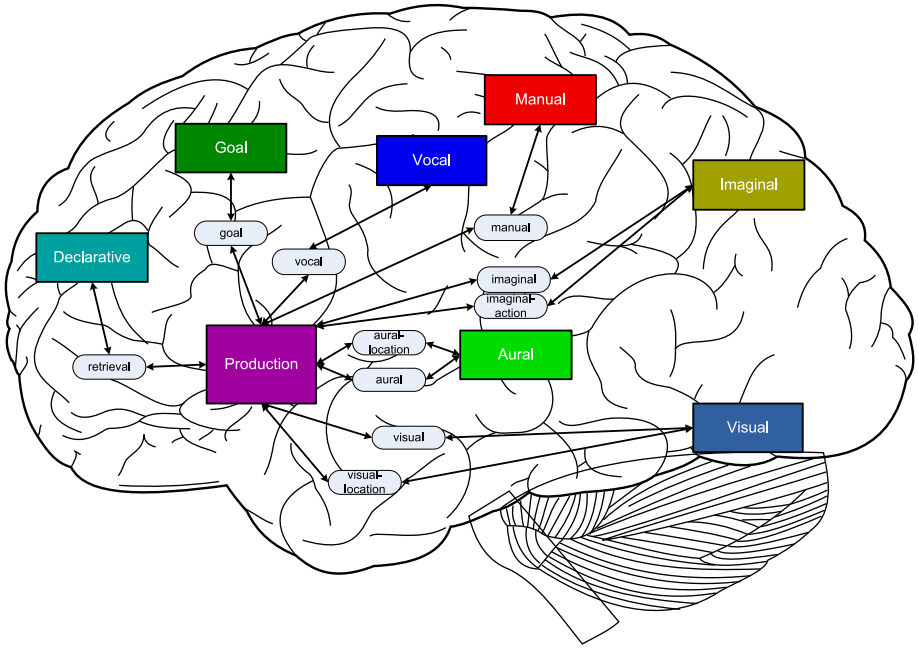

Fig. 2. ACT-R 6.0 modules and buffers with only approximate brain mapping for illustration purposes, after Anderson et al. (2008b).