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A cognitive architecture account of the visual local advantage phenomenon in autism spectrum disorders

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ABSTRACT

Ideally, a cognitive architecture is a neurally plausible model that unifies mental representations and cognitive processes. Here, I apply such a model to re-evaluate the local advantage phenomenon in autism spectrum disorders (ASD), that is, the better than typical performance on visual tasks in which local stimulus features are to be discerned. The model takes (a) perceptual organization as a predominantly stimulus-driven process yielding hierarchical stimulus organizations, and (b) attention as predominantly scrutinizing the hierarchical structure of established percepts in a task-driven top-down fashion. This accounts for a dominance of wholes over parts and implies that perceived global structures mask incompatible local features. The model also substantiates that impairments in neuronal synchronization – as found in ASD – reduce the emergence of global structures and, thereby, their masking effect on incompatible features. I argue that this explains the local advantage phenomenon and I discuss implications and suggestions for future research.

1. Introduction

Autism spectrum disorders (ASD) are complex neurodevelopmental disorders, the severity of which is based on social communication impairments and restricted repetitive patterns of behavior (American Psychiatric Association, 2013). In addition to these diagnostic features, ASD individuals also show atypical cognitive processing (for reviews, see Pellicano, 2011; Rajendran & Mitchell, 2007), particularly in the visual domain (for reviews, see Dakin & Frith, 2005; Simmons et al., 2009). An intriguing example of atypical visual processing in ASD is the local advantage phenomenon, that is, the better than typical performance on visual tasks in which local stimulus features are to be discerned – such tasks being, for instance, embedded figures tasks, block design tasks, and visual search tasks (Jolliffe & Baron-Cohen, 1997; Joseph et al., 2009; O'Riordan et al., 2001; Shah & Frith, 1983, 1993). Explanations of this phenomenon usually rely on either reduced global processing (promoted most prominently by Frith, 1989) or enhanced local processing (promoted most prominently by Mottron & Burack, 2001). Thus far, however, empirical data on this phenomenon seemed inconclusive as to which explanation prevails.

In this theoretical study – which, of course, relies on empirical data too – I first integrate various ideas and findings on typical perception and attention into a neurally plausible cognitive model, called PATVISH (acronym of Perception and ATtention in the VISual Hierarchy). Then, I investigate what reduced global processing and enhanced local processing would yield according to this model, and I re-evaluate evidence on these alleged deviations in ASD. I conclude that the local advantage phenomenon in ASD is primarily a side effect of reduced global processing caused by impaired neuronal synchronization, and I end with critical predictions. For instance, one of these predictions is that the local advantage phenomenon occurs only for local features that are incompatible with perceived global structures, that is, features that are not proper substructures of perceived global structures. To be clear, incompatible features are not to be confused with incongruent features in the sense of Navon (1977). This is illustrated in Fig. 1, in which perceived global structures are represented schematically above their constituent parts. It demonstrates that both congruent and incongruent features are compatible with perceived global structures. In the next section (with some material reproduced from van der Helm, 2012), I begin by discussing perception and attention in typical individuals.

2. Typical perception and attention

Attention can mean many things. For instance, in cognitive science, distinctions have been made between selective and divided attention (i.e., concentrated on a specific thing vs. divided

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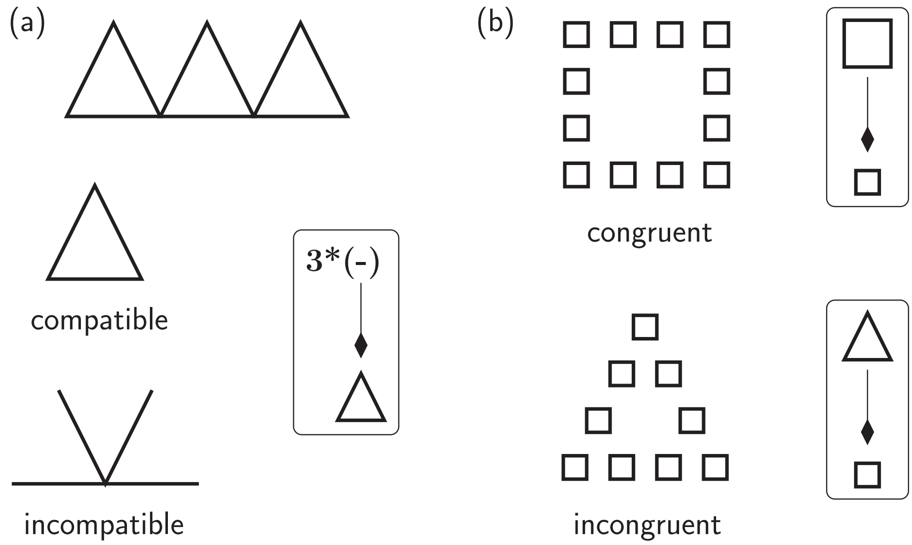

Fig. 1. Incompatibility vs. incongruency. (a) A stimulus whose perceived organization is a triplet of triangles, and parts that are respectively compatible and incompatible with this perceived organization. (b) Stimuli composed of compatible local elements that are respectively congruent and incongruent with the global structure (after Navon, 1977). The insets schematically represent the perceived hierarchical organizations, with global structures above their constituents parts.

over several things); between overt and covert attention (i.e., actively directed gaze vs. purely mental focus); and between exogenous bottom-up and endogenous top-down attention (i.e., drawn by stimuli like a bright flash vs. directed to stimuli in function of a task). These definitions overlap, but the form of attention considered in this study is specified best by task-driven top-down attention. Be that as it may, notice that attention – of whatever form and involving whatever action – is basically the allocation of processing resources (Anderson, 2004). In other words, it may decide what you focus on but not what you perceive before or after focusing. This is where perception comes in.

By perception, I mean visual perceptual organization. This is the neuro-cognitive process that enables us to perceive scenes as structured wholes consisting of objects arranged in space. This presumably automatic process may seem to occur effortlessly in daily life, but by all accounts, it must be both complex and flexible. Gray (1999) gave the following gist of it. For a proximal stimulus, the perceptual organization process usually singles out one hypothesis about the distal stimulus from among a myriad of hypotheses that also would fit the proximal stimulus (this is also called the inverse optics problem). This means that multiple sets of features at multiple, sometimes overlapping, locations in a stimulus must be grouped in parallel and that the process must cope with a large number of possible combinations simultaneously. This indicates that the combinatorial capacity of the perceptual organization process must be high, which, together with its high speed (it completes in the range of 100–300 ms), reveals its truly impressive nature.

The exact nature of the interplay between perception and attention is still unclear. Some hold that the perceptual organization process is purely stimulus-driven (e.g., Gray, 1999; Pylyshyn, 1999), while others hold that it is fully controlled by attention (e.g., Lamme & Roelfsema, 2000). As I specify next, my stance is close to the former but leaves room for attention to modulate the outcome of the perceptual organization process.

2.1. The cognitive architecture PATVISH

Cognitive architecture, or unified theory of cognition, is a concept from artificial intelligence (AI) research. It refers to a blueprint for a system that acts like an intelligent system – taking into account not only its resulting behavior but also physical or more abstract properties implemented in it (Anderson, 1983; Newell, 1990; for reviews, see Byrne, 2012; Langley, Laird, & Rogers, 2009; Sun, 2004). Hence, it aims to capture not only competence (i.e., what is a system's output?) but also performance (i.e., how does a system arrive at its output?). It therefore calls for a unification of dynamic processes (which include temporal factors) and static representations (which include structural factors).

Just as many recognized cognitive architectures – which come in various levels of detail and often focus on human language – PATVISH is not a full-blown model of human cognition as a whole. Yet, focusing on human perception and attention and taking behavioral and neurophysiological data into account, it does aim to unify cognitive processes and representations. Furthermore, it may not qualify as a typical AI model – as it is a verbal model (a blueprint) rather than an implemented model that can take actual input – but it is sustained by a full-blown computational model of a related issue (see below). More specifically, it incorporates the next picture of processes and representations in the visual hierarchy in the brain (for more details, see van der Helm, 2012, 2014, 2015).

According to Felleman and van Essen (1991), the neural network in the visual hierarchy is organized with 10–14 distinguishable hierarchical levels (with multiple distinguishable areas within each level), contains many short-range and long-range connections (both within and between areas and levels), and can be said to perform a distributed hierarchical process. In line with Lamme, Supèr, and Spekreijse (1998), PATVISH takes this process to consist of three neurally intertwined but functionally distinguishable subprocesses. As illustrated in the left-hand panel in Fig. 2, these subprocesses are responsible for, respectively, (a) feedforward extraction of, or tuning to, features to which the visual system is sensitive, (b) horizontal binding of similar features, and (c) recurrent selection of different features. As illustrated in the right-hand panel in Fig. 2, these subprocesses together yield integrated percepts given by hierarchical stimulus organizations.

In PATVISH, the resulting hierarchical organizations are taken to be the simplest ones, that is, organizations which – by exploiting visual regularities such as repetition and symmetry – can be specified using a minimum number of descriptive parameters. This simplicity principle (Hochberg & McAlister, 1953) is a descendant