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Fitting perception in and to cognition

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ABSTRACT

Perceptual modules adapt at evolutionary, lifelong, and moment-to-moment temporal scales to better serve the informational needs of cognizers. Perceptual learning is a powerful way for an individual to become tuned to frequently recurring patterns in its specific local environment that are pertinent to its goals without requiring costly executive control resources to be deployed. Mechanisms like predictive coding, categorical perception, and action-informed vision allow our perceptual systems to interface well with cognition by generating perceptual outputs that are systematically guided by how they will be used. In classic conceptions of perceptual modules, people have access to the modules' outputs but no ability to adjust their internal workings. However, humans routinely and strategically alter their perceptual systems via training regimes that have predictable and specific outcomes. In fact, employing a combination of strategic and automatic devices for adapting perception is one of the most promising approaches to improving cognition.

1. Introduction

Attempts to describe the interface between perception and cognition presume that perception and cognition can be separated from one another. It only makes sense to talk about the interface between processes A and B if they are, in fact, two separate, albeit linked, processes. Given the difficulties in sharply delineating between perception and cognition, some thinkers have been led to the radical move of completely lumping them together. With the notion of perception as unconscious inference, Helmholtz (1867) joined perception and cognition, with both crucially involving the interpretation of the world. The Buddhist mental factor Saṃjñā has been translated alternatively as "cognition" or "perception." Talmy (2000) advocated using the term "ceptions" to purposefully merge perception and conception, motivated by an effort to break down artificial boundaries between these mental acts. More recently, Clark (2013) has argued that "the lines between perception and cognition [are] fuzzy, perhaps even vanishing" (p. 190).

2. Adaptive perceptual modules

Still, there are good reasons to prefer construing perception and cognition as interactive, even overlapping, processes, but nonetheless differentiated. The brain is comprised of anatomically localized regions with relatively dense within-region neural connectivity and sparser between-region connectivity. Brain regions can often times be attributed specific perceptual tasks, such as the perception of color, binocular depth perception, reading, and face recognition. The articulation of the brain into modules such as these is crucial for achieving fast and reliable perception (Nakayama, 2005). Cases of cognitive impenetrability exist in which particular goals, expectations, and beliefs one has do not influence one's perception (Pylyshyn, 2003). More generally, there is a theoretical advantage to conceptualizing most active agents embedded in environments in terms of perception, cognition, and action. For extended and embedded agents from cars

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to people to webpages to aircraft carriers, it is useful to think of some components playing primarily information processing roles, and some as primarily processing the specific nature of the environmental information. Our conceptualization of conceptualization itself should not become so blended with perception that the evidence for and conceptual advantages of partially independent perceptual modules are lost.

Granting the existence of perceptual modules does not commit one to the assumption that these modules are hardwired or fixed in their function. In fact, perceptual modules are highly adaptive and become attuned across several temporal scales to the cognitive needs of an organism. At the longest, evolutionary time scale, organisms evolve perceptual systems that are tailored to their stable environment. A compelling case of this is the close match between the peak light wavelength sensitivity of photoreceptors in fish to the most prominent wavelengths in their water environments (Lythgoe, 1972). At the intermediate time scale of learning throughout an organism's lifetime, perceptual modules become tuned to frequently recurring patterns. At the most rapid time scale of moment-to-moment changes in context, responses in our earliest perceptual systems become modified by expectancies (Lupyan & Ward, 2013). For example, training in a selective attention task produces differential responses as early as the cochlea (Puel, Bonfils, & Pujol, 1988). This amazing degree of top-down modulation of a peripheral neural system is mediated by descending pathways of neurons that project from the auditory cortex all the way back to olivocochlear neurons, which directly project to outer hair cells within the cochlea—an impressively peripheral locus of modulation.

Perceptual learning over the course of an organism's lifetime is a particularly powerful way of altering the functioning of perceptual modules so that they come to better serve an organism's cognitive needs. Even if humans are not consciously and strategically changing the "wiring" of perceptual modules (a possibility we will return to later), these modules nonetheless adapt systematically at the time scales of tens to thousands of repetitions to allow an organism to better make discriminations and categorizations that are vital to its interests. Empirical evidence points to neurophysiological changes to properly perceptual, rather than post-perceptual decision, brain regions. For example, when monkeys are trained with one of two visual discrimination tasks (a bisection task or vernier discrimination), their primary visual cortex (V1) neurons take on different novel function properties pertinent to these tasks even when presented with the same shape (Wu, Piëch, & Gilbert, 2004). These V1 differences are observable from the very earliest neural responses following stimulus onsets. Generalizing over many studies, training in both auditory and visual tasks produces early changes to many perceptual modules. One of the mechanisms for these changes are that neurons become more selective in their responses and the cortical representations of different features become increasingly less overlapping (Crist, Li, & Gilbert, 2001).

This evidence from neuroplasticity apparently clashes with epistemological concerns about perceptual systems being "tainted" by preconceptions. The concern is that if our perception of the world depends on our experiences and wishes, then how can these perceptions then provide us with unbiased evidence about the world (Siegel, 2012)? As Fodor (1983) puts it: "seeing what we expect seems to defeat the purpose of vision: [an organism] generally sees what's there, not what it wants or expects to be there. Organisms that don't do so become deceased" (p. 68). Hallucination is counterproductive.

The resolution to this apparent clash is that there is good reason to suspect that hallucination is in fact minimized when our perceptions *are* influenced by our cognitive requirements (Lupyan, in press). These requirements, again, will reflect evolutionary, life-long, and moment-to-moment needs. Occasionally, the needs of these temporal scales are inconsistent, producing noticeable perceptual effects (Anstis, Verstraten, & Mather, 1998; Barlow, 1990). Yet, on the whole, adaptation of the perceptual system to the demands of cognition increases the efficacy and efficiency of perceptual processing (Benucci, Saleem, & Carandini, 2013; Çukur, Nishimoto, Huth, & Gallant, 2013). The reason for perceptual learning on this view is that the needs of one specific member of a species might differ from other members' needs because of how it is making its idiosyncratic living. A father of identical twins needs to develop an ability to efficiently distinguish them that other people need not, and a radiologist needs to develop the ability to distinguish cancerous tumors from benign tissue at an expert level beyond the needs of most of humanity (Gauthier, Tarr, & Bubb, 2010). Borrowing from Fodor: organisms that waste their time seeing everything that is there, instead of perceiving relative to their expectations and needs, end up dead.

Researchers have described a "hierarchical predictive coding" account in which a cognizing system can have its perceptual encodings affected by its needs and experiences at every step of sensory transformation (Clark, 2013; Friston, 2010). What is perceived is a synthesis of the sensory input as it is best predicted by existing generative models at multiple levels, plus the aspects of the input that have not been successfully predicted by higher-level areas, and are thus providing feedback signals to adapt the generative models. The top-down generated predictions and error from these predictions seem to be represented in different areas (superior temporal sulcus and fusiform face area, respectively, in the case of face stimuli), providing support for this functional decomposition (Apps & Tsakiris, 2013). Although additional support for this approach is still needed, the benefits of a cognitive system that is perceiving inputs relative to its many-leveled expectations are clear, and plausible neural and computational implementations are available (Rao & Ballard, 1999; Spratling, 2008).

3. Making perception pertinent to cognition and action

There are many ways in which cognition and action become intertwined with perceptual processing. Researchers have identified and distinguished attentional orientation (changes in the inputs to the perceptual system,