Computational Cultural Neuroscience: Implications for Augmented Cognition

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Abstract. From perceiving objects in space to recognizing emotions at a distance, culture affects how people think, feel, reason as well as the neurobiological mechanisms underlying these processes. Here I review recent evidence from cultural neuroscience, introduce the notion of computational cultural neuroscience – the development of computational and formal models of how culture affects neurobiological mechanisms and vice versa – and finally, discuss the implications of computational cultural neuroscience for research in augmented cognition.

Keywords: cultural neuroscience; computational cultural neuroscience; augmented cognition.

1 Introduction

Over the past two decades, researchers in the field of augmented cognition have worked to develop novel technologies that can both monitor and enhance human cognition and performance. Much of this research in augmented cognition has relied on research findings from cognitive science and cognitive neuroscience, fields which seek to illuminate how the mind and brain work. Seminal findings from these fields, such as resource limitation capacities in working memory and attention, have enabled augmented cognition researchers to identify potential bottlenecks in human achievement and to develop technological solutions that overcome such limitations.

While notable advances have been made in the field of augmented cognition, recent advanced in the fields of cultural psychology and cultural neuroscience suggest that across a range of cognitive and perceptual abilities vary across cultures leading to the need for researchers across disciplines to determine ways to model and implement culturally-diverse technologies that can monitor and enhance human cognition and performance with efficacy across cultural groups.

In this paper, I will review recent empirical evidence in cultural psychology and cultural neuroscience demonstrating cultural variation in perceptual, cognitive and socioemotional processing. Next, I will describe ways in which formal computational models of cognition across cultures may facilitate the ability of augmented cognition researchers to design technologies that enhance how the human mind and brain work in individuals across diverse cultures.

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1.1 Cultural Influences on Behavior and Brain Function

A fundamental dimension that cultures vary on is *individualism* and *collectivism* [1-3]. Individualistic cultures encourage thinking of people as independent of each other. By contrast, collectivistic cultures endorse thinking of people as highly interconnected to one another. Individualistic cultures, such as the West, emphasize self-expression and pursuit of individuality over group goals, whereas collectivistic cultures, such as the East, favour maintenance of social harmony over assertion of individuality [1-3]. Cultural psychological research has shown that cultural variability in self-construal style affects a wide range of psychological processing, from how people perceive objects in the environment to how they think about the world around them and recognize the mental states of others.

Recent evidence from cultural neuroscience is demonstrating that culture affects not only behavior, but also brain function. Cultural neuroscience is an emerging research discipline that investigates cultural variation in psychological, neural and genomic processes as a means of articulating the bidirectional relationship of these processes and their emergent properties. Research in cultural neuroscience is motivated by two intriguing questions of human nature: how do cultural traits (e.g., values, beliefs, practices) shape neurobiology (e.g., genetic and neural processes) and behavior and how do neurobiological mechanisms (e.g., genetic and neural processes) facilitate the emergence and transmission of cultural traits?

The idea that complex behavior results from the dynamic interaction of genes and cultural environment is not new [4]; however, cultural neuroscience represents a novel empirical approach to demonstrating bidirectional interactions between culture and biology by integrating theory and methods from cultural psychology [5], neuroscience [6] and neurogenetics [7-9]. Cultural neuroscience aims to explain a given mental phenomenon in terms of a synergistic product of mental, neural and genetic events. Cultural neuroscience shares overlapping research goals with social neuroscience, in particular, as understanding how neurobiological mechanisms facilitate cultural transmission involves investigating primary social processes that enable humans to learn from one another, such as imitative learning. However, cultural neuroscience is also unique from related disciplines in that it focuses explicitly on ways that mental and neural events vary as a function of culture traits (e.g., values, practices and beliefs) in some meaningful way. Additionally, cultural neuroscience illustrates how cultural traits may alter neurobiological and psychological processes beyond those that facilitate social experience and behavior, such as perception and cognition.

For instance, cultural variation between Westerners and East Asians affects how people think about themselves and their relation to the environment not only affects human behavior, but underlying neurobiological processes. For instance, Westerners engage brain regions associated with object processing to a greater extent relative to East Asians who are less likely to focus exclusively on objects within a complex visual scene [10]. Westerners show differences in medial prefrontal activity when thinking about themselves relative to close others, but East Asians do not [11]. Activation in frontal and parietal regions associated with attentional control show greater response when Westerners and East Asians are engaged in culturally preferred judgments [12]. Evolutionarily ancient limbic regions, such as the human amygdala, respond preferentially to fear faces of one's own cultural group [13]. Brain regions associated with social cognition, or thinking about what others are thinking, such as the superior temporal sulcus, show greater response when inferring the mental states of members of one's own cultural group [14]. Taken together, these findings show cultural differences in brain functioning across a wide variety of psychological domains and demonstrate the importance of comparing, rather than generalizing, between Westerners and East Asians at a neural level.

2 Computational Cultural Neuroscience

The existence of cultural variation in neural systems presents a novel opportunity and challenge for the development of a *computational cultural neuroscience*. Computational modeling of human brain and behavior provide a potent way to develop and test formal theories of the multilayered, complex and dynamic relation between cellular and network properties of neurons to mental representations that guide how people think and behave [15].

While computational modeling, in principle, allows for the development and testing of a multitude of theories regarding the relation between neural and behavioral systems, growing evidence from cultural neuroscience regarding how culture affects the human brain and vice versa represents a key advance allowing for the emergence of a computational cultural neuroscience. By knowing which neural systems show modulation of activation by cultural values, practices and beliefs and how systematic cultural modulation of neural systems alters human behavior, we gain important insights into fundamental structural and functional constraints underlying formal mathematical models of cultural influences on mind, brain and behavior.

Ultimately, by combining cultural neuroscience evidence with computational modeling, we may uncover an array of distinct formal models that capture the basic informational processing mechanisms underlying how people think, feel and behave across a diversity of human cultures. One important challenge in this endeavor is determining guiding principles that help to constrain and characterize the range of influence of culture on neurobiological systems (e.g., what aspects of the informational processing systems are universal or distinct across cultures and why). Another important challenge is distinguishing formal models of cultural influences on brain and behavior from formal models of individual differences in brain and behavior (e.g., what aspects of the informational processing systems represent individual versus group differences in brain-behavior relations).

2.1 Three Starting Points for a Computational Cultural Neuroscience

Here I describe three examples of a computational cultural neuroscience approach to understanding how and why structure-function mapping may vary across cultures. The first structure-function mapping that may vary across cultures exists within subregions of the occipitotemoral cortex, which is responsible for the learning and representation of complex visual recognition, including objects, places and faces. Recent evidence from cultural neuroscience indicates that cultures vary in the extent to which neural responses within occipitotemporal cortex vary within fusiform gyrus and occipitotemporal gyrus, but not parahippocampal gyrus. For instance, Goh and colleagues [16] showed that activity within object-processing and object-scene binding in the ventral visual area varies across cultures. While encoding complex visual scenes consisting of objects embedded within a background, Caucasian-Americans and East Asians varied in the extent to which they showed increased neural response within ventral visual regions. More specifically, recent neuroimaging evidence shows that visual processing of complex visual scenes in Caucasian-Americans is more object-focused compared to East Asians and to facilitate this variability in attention and encoding towards objects compared to the background, neural response within object processing brain regions, such as lateral occipital cortex, is significantly heightened in Caucasian-Americans compared to East Asians. This variability in the degree to which occipitotemporal cortex is recruited during scene encoding reflects group differences in neural connectivity underlying attentional and memory processes. Future work in computational cultural neuroscience is needed to test formal models of how cultural variation in engagement of ventral visual regions during object processing arises from cultural differences in the type or kind of neural representation of objects and scenes within this region or merely reflects differential recruitment of core object processing regions universal across both groups.

Additionally, Gutchess and colleagues [10] recently showed that brain regions within fronto-parietal regions, including the right angular gyrus and right middle frontal gyrus, reveal cultural differences in neural response during semantic categorization. For instance, East Asians show increased neural response when categorizing semantic relations as a function of relation and category compared to Caucasian-Americans. Additionally, during semantic conflict trials compared to match trials, East Asian participants, showed greater response within a frontal-parietal network previously implicated in controlled executive function, whereas Caucasian-Americans, who showed increased response within the temporal lobe and cingulate gyrus, a brain region engaged during cognitive conflict. This variability in neural response suggests that cultural modulates the strength of network connectivity of fronto-parietal and temporo-cingulate connectivity during semantic categorization. Future work in computational cultural neuroscience is needed to test formal models of the extent cultural variation in network connectivity between these two cortical circuits arises from differences in feedforward or bidirectional neural connectivity.

Cultural variation exists not only with cortical regions underlying perception and cognition, but also socioemotional processes associated with emotion recognition and mental state inference. For instance, the human amygdala is a subcortical brain region which dense innerconnectivity with cortical regions and is specialized for recognition of emotional and social information [17]. Prior affective neuroscience studies have shown that the amygdala is critical to fear recognition and in particular the inferences of emotional states from the eye region of the face [17]. The ability to infer the mental states of others also recruits lateral brain regions such as the superior temporal sulcus that decodes social information from perceptual information within the face, including the eye, nose and mouth region. Recent evidence from cultural neuroscience suggests that Chiao and colleagues [13] showed that evolutionarily ancient limbic regions, such as the human amygdala, respond preferentially to fear faces of one's own cultural group. Additionally, brain regions associated with social cognition, or thinking about what others are thinking, such as the superior temporal sulcus, show greater response when inferring the mental states of members of one's own cultural group [14]. In both instances, these brain regions engaged during socioemotional processing show heightened response to culturally-familiar social signals. One important question that computational modeling can provide insight on is the extent to which this heightened processing for own-culture social stimuli is a function of cultural differences in perceptual information within the stimulus (e.g., template arrangement of facial signals) that activates a fixed or template-like neural representations within these regions. Alternatively, increased neural recruitment of amygdala and superior temporal sulcus for culturally-congruent perceptual information could simply reflect a learned neural response to a specific stimulus that remains flexible or dynamic to a wide range of perceptual input at certain period of development but then tunes with experience.

3 Implications for Augmented Cognition

While much work lies ahead in developing a computational cultural neuroscience approach to human brain and behavior, the implications of such an approach are numerous, particularly for the field of augmented cognition. A chief concern in developing novel technologies that increase human performance and decision-making is determining whether or not such technologies will adapt readily, with similar efficiency and accuracy, to human users who vary in cognitive styles due to cultural differences. To address this problem, augmented cognition researchers may use models from computational cultural neuroscience to engineer culturally-flexible technologies, achieving the goal of enhancing human cognition and socioemotional processing across culturally diverse populations.

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