Opinion

A Culture–Behavior–Brain Loop Model of Human Development

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Increasing evidence suggests that cultural influences on brain

bines

individual and population levels. The CBB loop model advances our understanding of the dynamic relationships between culture, behavior, and the brain, which are crucial for human phylogeny and ontogeny. Future brain changes due to cultural influences are discussed based on the CBB loop

Trends Cultural neuroscience research cor

interact with genes to shape

Enters the Culture Arena

Why do people in culturally-distinct societies behave differently? This fascinating question has been studied extensively in psychology by examining human cognitive and affective processes across **cultures** [1,2]. For example, one line of research that compares individuals from East Asian and Western cultures has revealed that East Asians tend to attend to contexts and relationships between objects [3,4], categorize objects in terms of their relationships [5], emphasize contextual effects during causal attribution of physical and social events [6,7], view the self as being interdependent with significant others and social contexts [8,9], and prefer low-arousal positive affective states [10]. By contrast, individuals from Western cultures are inclined to attend to a focal object, categorize objects by their internal attributes, emphasize individuals' internal dispositions during causal judgments, view the self as being independent of others and social contexts, and favor high-arousal positive affective states. These findings support a conceptual framework that **collectivistic** East Asian cultures foster a holistic thinking style whereas **individualistic** Western cultures cultivate an analytic thinking style [11].

Because mental activity is underpinned by the neurobiology of the brain that is shaped by experience [12], increasing interest has emerged in the discovery of brain activities that underlie cultural differences in mental processes and behaviors. Viewing culture as beliefs and behavioral scripts that are shared by a group of individuals and constitute social environments [13], cultural neuroscience combines cultural psychology and neurophysiological measures [e.g., **functional magnetic resonance imaging** (fMRI) and **event-related potentials** (ERPs), see Glossary] to investigate whether and how cultural contexts/experiences shape the functional organization of the human brain and to what degree culturally-distinct patterns of behavior are linked to different neural correlates across [13–19].

responses between individuals from East Asian and Western cultures in association with visual perception [20–22], attention [23,24], causal attribution [25], processing semantic relationships [26], processing music [27,28], mental calculation [29], self-face recognition [30,31], self-reflection [32–36], perception of body gesture [37], mental state reasoning [38,39], empathy [40,41], and trait inference [42] (Box 1). Researchers have also investigated the role of a specific cultural trait in mediating individual differences [33,35] and cultural group differences in brain activities [24,36,42]. Studies of **cultural priming** (Box 1) have shown that reminding participants in laboratory studies of specific East Asian/Western cultural values, such as independence versus interdependence, modulates brain activity during tasks that engage pain perception [43], visual perception [44], self-face recognition [45], self-reflection [46–48], motor processing [49], and brain activity during a resting state [50].

The increasing number of cultural neuroscience findings propels a conceptual framework that integrates dynamic interactions between culture and the brain to elucidate (i) how culture shapes the brain by contextualizing behavior, and (ii) how the brain modifies culture via behavioral influences. Such a framework is important for understanding how genes and culture shape the brain during long-term **gene–culture coevolution** and during lifespan **gene $\times$ culture interactions**. There have been profound discussions of the di7(d/F31Tf.566900-.5669132.8165053346ng)75()Tj/F51Tf8.9663008.966395.685

The CBB Loop Model of Human Development

The CBB Loop Model

The CBB loop model, as illustrated in Figure 1, posits that novel ideas are created by individuals and are diffuse in a population through social interactions in a specific ecological environment to become dominant shared beliefs and behavioral scripts that influence and contextualize human behavior. The functional and/or structural organization of the brain, owing to its inherent plasticity, changes as a consequence of absorbing cultural values and performing culturally patterned behaviors. The modified brain then guides individual behavior to fit into specific cultural contexts, and also modifies concurrent sociocultural environments. The CBB loop model proposes two types of behaviors. Culturally contextualized behavior (CC-behavior) refers to overt actions that are mainly governed by a specific cultural context, such as when a Chinese student who is accustomed to accepting a professor's opinion in China arrives in the USA and imitates American students to argue with a professor. CC-behavior may not occur when leaving a specific cultural environment. Culturally voluntary behavior (CV-behavior) denotes overt actions that are guided by specific cultural beliefs/values and behavioral scripts that are encouraged by a specific cultural environment and are embedded in the brain. For example, after the Chinese student has studied in the USA for a long time, and has internalized Western cultural values such as independence, he may default to arguing with a professor, regardless of the actions of his peers. CV-behaviors can occur independently of a specific cultural context if the cultural system in the brain remains stable to some degree.

The CBB loop model also distinguishes between two types of culture–brain interactions. Behavior-mediated culture–brain interaction refers to the interplay between culture and brain via overt behavioral practice. For instance, Western cultural values such as independence in the USA encourage the Chinese student to argue with his professors, and practicing such behaviors influences his brain. Direct culture–brain interaction refers to the interplay between culture and brain that does not involve overt actions. For example, reminding individuals of specific cultural values such as independence or interdependence in a laboratory setting can directly modulate brain activity. Thus, in the CBB loop model, behavior is not simply considered as a consequence of culture–brain interaction. Instead, behavior is considered as a part of the mechanisms of human development. The three key nodes, culture, behavior, and the brain, dynamically interact through their mutual connections and constitute a loop. Each node, and the connection

Individualism: a basic cultural element that emphasizes the importance of independence, one's own goals/preferences, needs/desires, and rights in thought and behavior. People in an individualistic culture give priority to personal rather than to group goals.

Independent self-construal: the cultural trait of viewing the self as autonomous and bounded entity, emphasizing independence and uniqueness of the self.

Interdependent self-construal: the cultural trait of viewing the self as interconnected and overlapping with close others, emphasizing harmony with close others.

Medial prefrontal cortex (mPFC): the medial region of the prefrontal cortex that is involved in social cognition, with the dorsal part being engaged in mental state reasoning and the ventral part engaged in self-reflection.

Temporoparietal junction (TPJ): a brain region at the border of the posterior parts of the temporal lobe and the inferior parts of the parietal lobe. This brain region is engaged in taking the perspective of others and inferring their mental states.

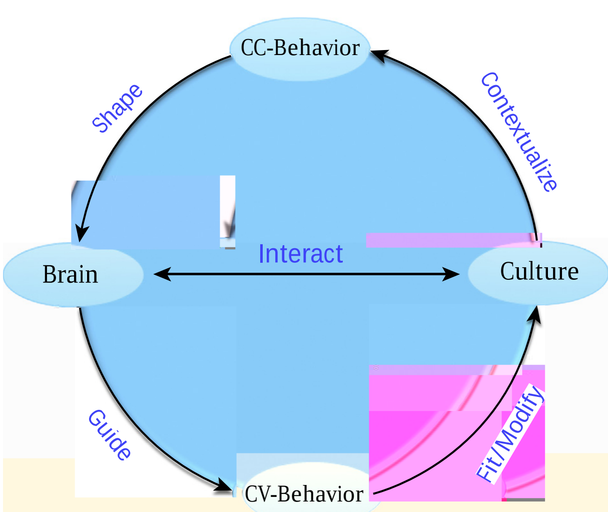

Figure 1. Illustration of the CBB Loop Model of Human Development. Cultural environments contextualize human behaviors. Learning novel cultural beliefs and the practice of different behavioral scripts in turn modify the functional organization of the brain. The modified brain then guides individual behavior to voluntarily fit into a cultural context and meanwhile to modify current cultural environments. Direct interactions also occur between culture and brain without overt behavior. Abbreviations: CBB, culture–behavior–brain, CC-Behavior, culturally contextualized behavior; CV-Behavior, culturally voluntary behavior.

between two nodes of the CBB loop, vary continuously across time and influence human phylogeny and ontogeny.

To illustrate human development in the CBB loop framework, let us consider a key cultural trait (i.e., interdependence/independence) beliefs that farming would supply more food produced one motivation for transition from gathering/hunting to farming during the Agricultural Revolution [59]. There are many behavioral differences in contemporary individualism/collectivism societies that developed as adaptations to the environment [60]. As an example, at the individual level, parents who believe/value independence in an individualistic society may put their children to sleep in separate bedrooms after birth, whereas parents who believe/value interdependence in a collectivistic society may share a bedroom with their children until early adulthood [61].

reward-related activity in the bilateral ventral striatum in response to winning money for a friend during a gambling game [74]. Priming interdependence versus independence decreased early sensory responses to painful electric shocks [43], increased motor-evoked potentials induced by transcranial magnetic stimulation during an action observation task [49], and increased local synchronization of spontaneous activity in the dorsal region of the mPFC – but decreased local synchronization of spontaneous activity in the posterior cingulate cortex during a resting state [50].

These findings indicate that both long-term and short-term cultural experiences influence the brain activity involved in multiple mental processes, and provide evidence for interactions

Key Figure

Illustration of the Relationship Between Genes and the CBB loop

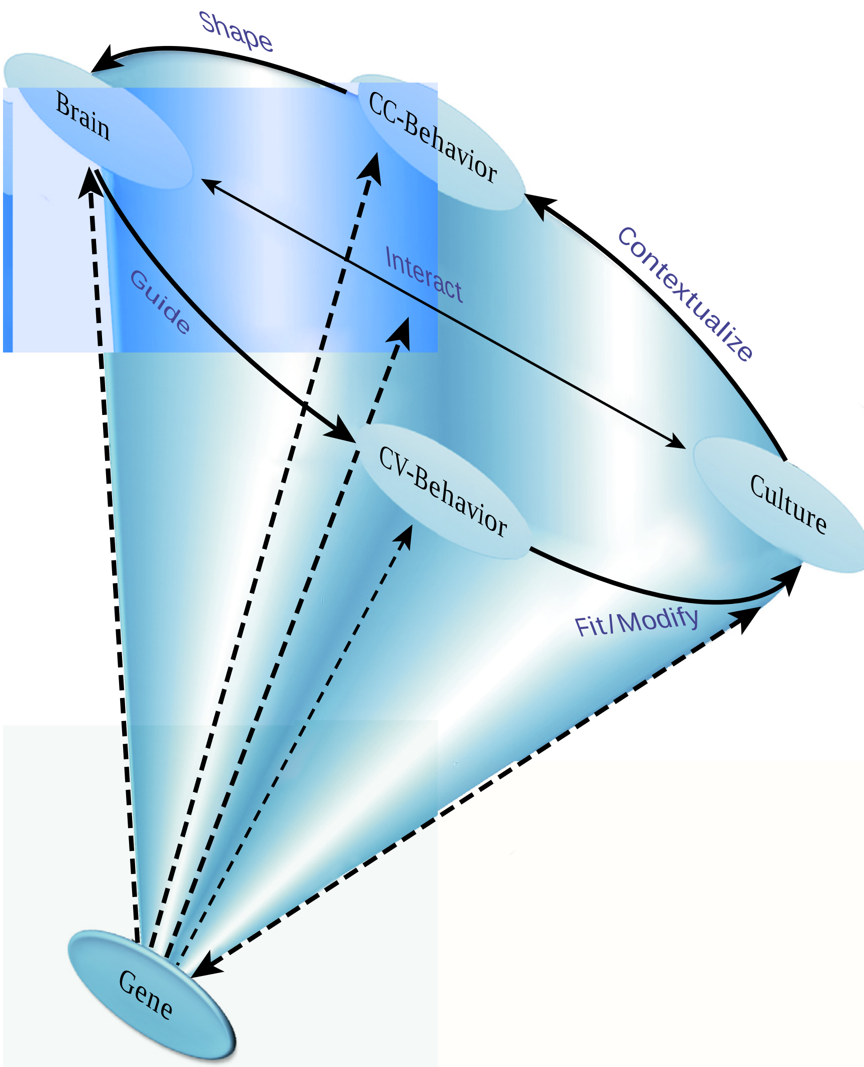

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Figure 2. Genes provide a fundamental basis for the CBB loop in several ways, including genetic influences on the brain and behavior, mutual interactions between genes and culture, and genetic moderations of the association between brain and culture. The unbroken lines in the CBB loop indicate fast interactions between two nodes, whereas the broken lines linking genes and the CBB loop indicate slow interactions between genes and the CBB loop. Abbreviations: CBB, culture–behavior–brain; CC-Behavior, culturally contextualized behavior; CV-Behavior, culturally voluntary behavior.

cultural and behavioral influences on the brain occur much faster (e.g., lifespan) [62]. Cultural priming on the timescale of minutes in a laboratory setting can even induce functional changes of brain activity during a variety of tasks [43–50]. Given that the brain changes associated with genetic and cultural factors operate at different speeds, we suggest that genes interact with the CBB loop by providing a fundamental basis for the CBB loop in several ways, as illustrated in Figure 2

(Key Figure). First, genes shape human brain anatomy by influencing its size [79,80], affecting both cortical and subcortical structures [81,82], and shaping the functions of specific brain regions [83,84]. Second, twin and adoption studies have demonstrated that some behavioral/cognitive characteristics are heritable [85]. Candidate-gene and genome-wide association studies have linked genes to behaviors that are thought to be culturally determined (e.g., smoking and schooling) [86,87]. Third, our environment and experience strongly constrain how genotypes give rise to behavioral phenotypes [88]. Moreover, the link between genes and behavior is expressed in different or even opposite patterns in East Asian and Western cultures [89,90], and cultural difference in social orientations (e.g., interdependence) exist in one variant but not another variant of the same gene [91]. These findings indicate gene × culture interactions on behavior and psychological traits. Finally, the brain activity in responses to self-reflection

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take a recent example, the rapid growth of internet commerce and communication has created 'an internet culture' [77] that has changed human behaviors substantially and may lead to modifications of brain function. For instance, the internet search engines allow students to access a large body of literatures from internet databases. They now have to learn where and how to access these literatures rather than to remember their contents [99]. Thus, the neural structures that are currently used to store and retrieve semantic knowledge (e.g., the inferior frontal cortex, inferior parietal lobe, and temporal lobe) [100,101] may be endowed with other functions such as inference of causal relationships [25] in the next generation. Another consequence of the emerging internet culture is the abatement of close-distance face-to-face communications that allow humans to develop unique neural activity supporting reactivity to the cognitive and affective mental states of others [102]. Children who increasingly rely on internet/smartphone communication may spend less time engaging in close-distance face-to-face interactions, which may in turn influence brain activity in the mPFC, TPJ, and anterior cingulate – areas related to the inference of others' mental states and empathy [38–41]. Internet and smartphone also keep people continuously digitally connected and this 'always-on' culture [78,103] leads to a high level of discontinuity in the execution of activities [104] related to multiple tasks that may bring various changes of the brain functions of the frontal and parietal lobes related to attention [105]. These potential changes of brain functions, which should be tested in future empirical research, may help the next generation to easily fit into the internet culture and, meanwhile, the brain shaped by the internet culture may produce new behavioral scripts (e.g., online shopping and social networking) that may modify the contemporary sociocultural environment.

Concluding Remarks

Although cultural neuroscience findings related to the CBB loop model of human development are mainly derived from studies of individuals from East Asian/Western cultures, this model can advance our understanding of the relationships between culture, behavior, and the brain in general. The CBB loop model gives prominence to the dynamic features of CBB interactions that allow continuous changes of culture, behavior, and the brain. The CBB loop model proposes cultural and genetic modifications of the functional organization of the brain along different timescales, and this has important implications for understanding the role of the brain in bridging the gap between gene and culture during gene-culture coevolution and gene $\times$ culture interactions. The dynamic properties of the CBB loop also have implications for comprehending human success during evolution. The CBB loop model helps us to predict future changes of human brain function as a result of emergence of new culture, and raises new questions for future research (see Outstanding Questions).

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