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A Call for Greater Attention to Culture in the Study of Brain and Development

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Abstract

Despite growing research on neurobiological development, little attention has been paid to cultural and ethnic variation in neurodevelopmental processes. We present an overview of the current state of developmental cognitive neuroscience, with respect to its attention to cultural issues. Analyses based on 80 publications represented in 5 recent meta-analyses related to adolescent developmental neuroscience show that 99% of the publications utilized samples in Western countries. Only 22% of studies provided a detailed description of participants' racial/ethnic background and 18% for socioeconomic status. Results reveal a trend in developmental cognitive neuroscience research: not only is this body of research mostly derived from Western samples, but the race/ethnicity of the majority of participants is unknown. To achieve a holistic perspective on brain development in different cultural contexts, we propose and highlight an emerging interdisciplinary approach – developmental cultural neuroscience – the intersection of developmental psychology, cultural psychology, and cognitive neuroscience. Developmental cultural neuroscience aims to elucidate cultural similarities and differences in neural processing across the lifespan. We call attention to the importance of incorporating culture into the empirical investigation of neurodevelopment.

The advent of magnetic resonance imaging (MRI) has provided unprecedented opportunities for the study of human brain structure and function *in vivo*. Since the very first MRI scans of the developing human brain in the 1990s (Casey et al., 1995; Giedd et al., 1996; Giedd et al., 1999; Reiss, et al., 1996), we have made tremendous progress in understanding the neural processes supporting youth's development (for reviews, see Blakemore & Mills 2014; Crone & Dahl, 2012; Dahl, Allen, Wilbrecht, & Suleiman, 2018; Decety & Meyer, 2008; Goldsmith, Pollak, & Davidson, 2008; Lee et al., 2014; Somerville & Casey, 2010; Steinberg, 2008). In parallel, decades of research from developmental psychology, anthropology, and sociology, underscore how youth's developmental trajectories are shaped, in large part, by sociocultural contexts (e.g., Chen, 2018; Greenfield & Suzuki, 1998; Mead 1928; Rogoff, 2003; Schlegel & Barry, 1991). Yet, culture is largely absent in the field of developmental cognitive neuroscience, resulting in a biased understanding of what

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constitutes normative developmental trajectories. We call attention to the importance of incorporating culture into the empirical investigation of neurodevelopment.

Culture in Development

Culture is a system of values, beliefs, and practices that constitute one's environment, which is shared by a certain group (geographical, social) and transmitted across generations via repetitive engagement (Causadias, Telzer, & Gonzales, 2017; Markus & Kitayama, 2010; Kitayama & Salvador, 2017; Kitayama, Varnum, & Salvador, 2018). Therefore, culture provides a framework in which individual cognitions and behaviors are understood, realized, and made meaningful, and thus, in which they function. In the psychological sciences, culture is frequently conceptualized and operationalized at different levels, such as nationality, race/ethnicity, socioeconomic status, and beliefs (e.g., collectivist values) (e.g., Markus & Kitayama, 1991; Triandis, 1995; Stephens, Markus, & Phillips, 2014). Culture plays a powerful role in child development, shaping developmental trajectories in academic, cognitive, social, and emotional functioning, via social contexts in which development occurs, such as parent-child relationships, teacher-child interactions, and peer relations (e.g., Chen, 2018; Greenfield & Suzuki, 1998; Mead 1928; Rogoff, 2003; Schlegel & Barry 1991; Stevenson & Lee, 1990). Indeed, scholars argue that for a neurologically healthy newborn, the *single* most important determinant for development is the cultural context in which the child lives, because every aspect of development is influenced by culture (Weisner, 2002, 2013). Culture determines economic security, access to resources for providing nutrition, norms and practices regarding nursing, sleeping arrangements, infant-directed speech, and daily routines (Weisner, 2002). For example, youth in low socioeconomic families encounter more obstacles for school achievement, cognitive development, physical and mental health resources (e.g., Bradley & Corwyn, 2002; Brooks-Gunn & Duncan, 1997; McLoyd, 1998; Sirin, 2005). Transitional periods in development, for example, from childhood to adolescence, may also vary across cultures. For instance, the so-called "storm and stress" of adolescence, which includes heightened parent-child conflict, mood disruptions, and risk-taking behavior, is less evident in non-Western cultures than Western cultures (Arnett, 1999; Mead, 1928; Schlegel & Barry, 1991). Together, past research on culture and development consistently underscores that child development is shaped, in large part, by cultural contexts.

The Importance of Integrating Culture into the Study of Brain and Development

Despite a long history of incorporating culture into the study of youth's behavioral and psychological development, and more recent cultural neuroscience research incorapting culture into the study of brain function, little is known about the role of culture in youth's brain development. Recent advances in cultural neuroscience demonstrate important differences in neural function and structure among adults across cultures (see Chiao, 2009; Han & Ma, 2015; Han et al., 2013). For instance, cultural differences emerge in social domains such as theory of mind (Frank & Temple, 2009), social comparison (Kang, Lee, Choi, & Kim, 2013), and social reward sensitivity (Varnum, Shi, Chen, Qiu, & Han, 2014),

as well as self-construal (Han & Humphreys, 2016), emotion generation and regulation (Chiao, 2015; Tsai & Qu, 2018), face perception (Freeman, Rule, & Ambady, 2009), and working memory (for reviews, see Chiao & Ambady, 2007; Han & Ma, 2014; Han et al., 2013; Kim & Sasaki, 2014; Kitayama & Uskul, 2011). Although such evidence suggests the possibility that cultural experience can lead to changes in the function and structure of the human brain, the majority of this research has been done in adults, leaving open the question of when and how the brain becomes tuned to process the world differently based on cultural experiences.

Thus, it is essential to incorporate development in cultural neuroscience research (Chiao, 2018). A comprehensive understanding of cultural shaping of the brain requires research from a developmental perspective. It remains unclear *when* cultural differences in neurobiological processes emerge across development, *why* culture plays a role in the developing brain, and *how* culture is wired into the brain via socialization processes conveying cultural values and beliefs. Instead of treating cultural influence as static, adding a developmental angle can address these issues and capture the dynamic process of cultural shaping of the developing brain over time. Understanding developmental processes helps researchers move from simply documenting cultural differences to unpacking how culture exerts its influence (e.g., Bond, 2002; Bukowski & Sippola, 1998; Heine & Norenzayan, 2006). Moreover, empirical investigations of how cultural inputs affect the developing brain will provide new insights into the brain's plasticity and malleability from childhood to adulthood. Therefore, it is important to integrate culture, brain, and development to achieve a comprehensive and integrative perspective on how diverse cultural environments influence child development, and to broaden our understanding of cultural transmission and neural plasticity. This paper seeks to give a more comprehensive review of related literature and propose a framework to help inspire and organize future research in this area.

The Current Representation of Culture in the Study of the Developing Brain

While culture has a long history of consideration in psychology, it has been largely overlooked in research utilizing cognitive neuroscience tools to study the developing brain. In particular, culture is absent in terms of (1) including diverse and representative samples of youth, (2) comparing cultural groups to better understand differences and similarities in neural processes at the group level, and (3) examining individual-level cultural systems and values. It is important to note that the oversight of culture in the field of psychology in general has been widely identified and acknowledged by scholars (e.g., Arnett, 2008; Henrich, Heine, & Norenzayan, 2010). In order to understand the current representation of culture in developmental cognitive neuroscience research, we conducted a review of recent influential publications (see Supplementary Table 1) to examine the presence of diverse samples, including regional diversity, ethnic/racial diversity, and socioeconomic diversity. We identified these studies from recent meta-analyses on topics related to adolescent developmental neuroscience, including reward processing (Silverman, Jedd, & Luciana, 2015), decision-making in social contexts (van Hoorn, Shablack, Lindquist, & Telzer, 2019), social exclusion (Vijayakumar, Cheng, & Pfeifer, 2017), risky decision making (Defoe, Dubas, Figner, & van Aken, 2015), and a review article on real-world risk taking (Sherman, Steinberg, & Chein, 2019). Though not comprehensive of all developmental cognitive

neuroscience research, these studies provide a snapshot of recent influential publications in the field.

From these meta-analyses, we identified 80 studies, which included a total of 3,704 adolescent participants. We examined the participant demographics for each study in terms of regional location, racial/ethnic background, and socioeconomic status (SES; i.e., parental education, income, employment status, occupational prestige). Regional location was coded as Western (i.e., Western Europe or the United States) vs. non-Western (i.e., Asia, South America), and US vs. non-US. Reports of race/ethnicity and SES were categorized as being detailed (i.e., provided full description including specific numbers for each race and at least one measure of SES), incomplete (e.g., "majority of participants were White" or "participants were from middle to upper-middle class families"), or not reported.

Table 1 presents the percentages based on the total number of studies (N=80). The majority of studies utilized samples in Western countries (99%), particularly the US (65%). Only 22% of studies provided a detailed description of participants' racial/ethnic background and 18% for SES. Of the detailed reports of SES, two studies reported parental education and income, two reported parental income only, two reported parental education only, one reported parental income and employment status, and seven used a composite measure of social class that assesses parental marital status, employment status, education, and occupational prestige. The diversity of SES measures precludes our ability to synthesize the representation of SES across studies. For the studies that reported detailed information on race/ethnicity, we examined the representation of each racial/ethnic group. Figure 1 presents the percentages for each racial/ethnic group based on the total number of participants across all 80 studies (N=3704). No racial/ethnic information was reported for 2933 (79.2%) participants. Of the 771 participants with detailed racial/ethnic information, 458 (59.4%) were White/European American, 55 (7.1%) were Black/African American, 122 (15.8%) were Latinx/Hispanic, 59 (7.7%) were Asian/Asian American, and 77 (10%) were Mixed/Other. Of the 2933 participants for whom no information was reported, 932 (31.8%) came from US samples and 2001 (68.2%) came from Western European samples (i.e., Netherlands, UK, Spain, Germany, and Finland). In addition to race/ethnicity and SES, over half the studies (51%) reported sample demographic information relating to intelligence (see Supplementary Table 1).

Results from this review reveal a trend in developmental cognitive neuroscience research: not only is this body of research mostly derived from Western samples, but the race/ethnicity and SES of the majority of participants is unknown. While individual differences in some important individualized demographic information, including participants' intelligence, tend to be reported more frequently, demographic information that might indicate cultural variation is more rare, making it difficult to draw conclusions about cultural similarities and differences in adolescent brain development. Although understanding sample characteristics in regards to intelligence is important for measuring normative developmental processes, this focus may have led to an underestimation/under-appreciation of the effects of social-cultural factors. It is understandable that many neuroimaging studies are unable to directly compare cultural groups due to small sample sizes and lack of statistical power. However, this review raises the importance of collecting and reporting culture-related information.

The oversight of culture in developmental cognitive neuroscience research makes bare two shortcomings. First, at the group level of culture, it remains an open question whether the patterns of neurodevelopment found in these studies are representative of normative developmental processes. For instance, the sample composition (e.g., ethnicity, age, sex, parental education, and income) can greatly influence developmental trajectories of brain development (LeWinn et al., 2017). For example, while the age at peak total cortical surface area is 12.1 years without taking into account sample demographics, such age peaks shift to 9.7 years (i.e., 2.4 years earlier) when weighting the sample with the approximate distribution of SES, race/ethnicity, and sex in the U.S. Census. Meanwhile, the developmental patterns for cortical surface area and subcortical volume change from U-shaped to S-shaped when applying a sample weighting method that makes the sample more representative. Thus, our fundamental understanding of normative brain development is biased based on the sampling methods used, and the current review suggests that much of the literature aimed at understanding the adolescent brain is largely based on Western samples of unknown racial/ethnic makeup.

Second, there is little to no understanding of the processes by which culture at the individual level (i.e., beliefs, values) influences and are influenced by the brain across development. Past research on adults suggests that individual level cultural beliefs may modulate neural function and structure (e.g., Ray et al., 2010; Kitayama et al., 2017; Wang, Peng, Chechlacz, Humphreys, & Sui, 2017). As subjective cultural beliefs may serve as an important source for individual differences in neural and psychological adjustment, more research is needed to incorporate culture into the understanding of individual differences in youth brain development. In order to gain an understanding of these issues and establish the foundation for interventions that foster healthy brain and psychological development across cultures, research must address the role of culture in brain development. To this end, we propose the conceptual approach of developmental cultural neuroscience.

Developmental Cultural Neuroscience: A Blending of Three Fields

To fully understand brain development in sociocultural contexts, we propose developmental cultural neuroscience, an emerging interdisciplinary approach that combines developmental psychology, cultural psychology, and cognitive neuroscience (Figure 2). Developmental cultural neuroscience aims to examine cultural similarities and differences in brain, psychological, and behavioral development across the lifespan. Past research has made tremendous progress by investigating the intersection of two of these fields, including developmental cognitive neuroscience (intersection of developmental psychology and cognitive neuroscience), developmental cultural psychology (intersection of developmental psychology and cultural psychology), and cultural neuroscience (intersection of cultural psychology and cognitive neuroscience). However, the intersection of all three of these fields is largely unexplored. Drawing on valuable approaches and insights from these three fields, developmental cultural neuroscience provides a framework that can address a variety of issues related to culture, development, and the brain that have not been examined previously.

To better understand the complex relationships between culture, brain, and development, we propose an overarching framework of developmental cultural neuroscience (Figure

3). Particularly important to this framework is the idea that culture shapes youth neurodevelopment via social practices and that these culturally shaped brain processes underlie differences in youth adjustment. Additionally, this framework considers the reciprocal links between culture, social practices, neurodevelopment, and youth outcomes, elucidating how cultural and neurobiological factors interact in the process of development. This theoretical framework is only an exploratory speculation based on current research. It is still an open question to test how culture plays a role in core developmental and neurobiological processes.

Culture, Social Practices, and Neurodevelopment

Decades of neuroscience research has demonstrated neuroplasticity and brain malleability – the ability of the brain to change across the lifespan. The developmental cultural neuroscience framework highlights the role of culture in this process, because cultural values and beliefs are embedded in a rich array of social practices, such as parent-child interactions, peer communication, and school activities (Kitayama & Uskul, 2011). For example, one key dimension of collectivistic beliefs shared in East Asian and Latin American families is family obligation, which entails children and adolescents' belief in the importance of supporting their family, assisting their parents, and making sacrifices for the sake of their family (e.g., Chao & Tseng, 2002; Ho, 1996; Qu & Pomerantz, 2015; Suárez-Orozco & Suárez-Orozco, 1995). This cultural belief guides many East Asian and Latin American youth's social practices in the family. Indeed, Latin American adolescents spend almost twice as much time helping their family each day compared to their European American counterparts, suggesting that family assistance is a meaningful daily routine for these adolescents to fulfill family obligation (Telzer & Fuligni, 2009).

Culture plays a key role in shaping youth's neurodevelopment via social practices. For example, Latin American adolescents—who endorse fulfilling family obligation more due to the cultural emphasis in their social environments—show more neural activation in the mesolimbic reward system when making decisions to contribute to their family that involve self-sacrifice, compared to European American adolescents who show more mesolimbic reward activation when gaining for themselves and not their family (Telzer et al., 2010). Thus, cultural differences in family obligation values and daily practices may contribute to divergent neural patterns in Latin American and European American adolescents. Indeed, adolescents with stronger family obligation values and who gain more happiness on a daily basis from helping their family show greater mesolimbic activation when making decisions to contribute to their family (Telzer et al., 2010; Telzer et al., 2016). A developmental cultural neuroscience approach provides initial evidence about how culturally rooted beliefs, shapes social practices, which in turn shape youth's neural processes.

Culturally Shaped Brain Processes and Youth Adjustment

Youth's neurodevelopment (e.g., neural function and structure), which is shaped by culturally rooted practices, further plays a key role in their behavioral and psychological adjustment. Such processes are important because the purpose of studying youth's brain development in cross-cultural settings is not just to document how brain development varies in different cultures, but also to examine how the neural underpinnings serve as

a mechanism that subsequently contributes to differences in youth's adjustment. Without understanding brain-behavior associations, the mean differences in neural activation between cultural groups is less meaningful. Therefore, it is critical to link culturally shaped neural activity with youth's real-life functioning, such as learning, school engagement, risk-taking behavior, and emotional well-being.

Guided by this framework, prior research investigated how culturally shaped neural processes among Latin American adolescents plays a role in their adjustment. For example, Latin American adolescents who report greater family obligation values show decreased activation in reward-related regions during risk taking and increased activation in cognitive control-related regions during behavioral inhibition (Telzer, Fuligni et al., 2013a). Importantly, the decreased reward activation is related to less real-life risk-taking behavior and increased cognitive control activation is related to better decision-making skills. Moreover, longitudinal research suggests that Latin American adolescents' mesolimbic reward activation when contributing to their family predicts longitudinal changes in their risk-taking behavior (Telzer, Fuligni et al., 2013b). Taken together, these findings suggest that family obligation – one key aspect of collectivistic values – guides adolescents to put the needs of their family before their own, influencing activation in neural regions involved in reward sensitivity and cognitive control, and such culturally shaped neural processes may help adolescents make optimal decisions and avoid engagement in risk taking in their everyday lives.

Such endeavors in identifying cultural differences in youth's neural processes and real-life adjustment will not only help us understand why cultural differences in youth's adjustment occur, but also provide insights into how to narrow the gap across cultures and promote optimal development. For example, there is much evidence that compared with their East Asian counterparts, American children and adolescents tend to show poorer performance in a variety of academic subjects, especially math and science (e.g., PISA, 2012; Stevenson, Chen, & Lee, 1993; TIMSS, 2011). Such differences in achievement are due, in part, to East Asian individuals' cultural emphasis on motivation and persistence in the face of difficult tasks compared to their Western counterparts (Heine et al., 2001). A recent neuroimaging study compared American and Chinese late adolescents' neural processes during cognitive persistence. The greater persistence in Chinese (vs. American) youth was paralleled by increasing activation and functional coupling between the inferior frontal gyrus (IFG) and ventral striatum (VS) across the task among Chinese but not American youth (Telzer, Qu, & Lin, 2017). These findings suggest that affective and cognitive systems may serve as key mechanisms underlying differences in cognitive persistence across cultures, and ultimately, contributing to cultural differences in youth's learning and academic achievement.

Reciprocal Relations between Culture, Brain Development, and Adjustment

The developmental cultural neuroscience framework also highlights the reciprocal relations between culture, brain, and adjustment. This is in line with the idea that culture and individual's adjustment are mutually constituted (Markus & Kitayama, 2010), as well as empirical evidence that youth are not only shaped by, but also shape their social environment (for reviews, see Belsky, 1984; Sanson & Rothbart, 1995). The essence of this reciprocal

perspective is that culture, brain, and youth's adjustment are not static but dynamically changing over time (Choudhury, 2010). Examining the reciprocal relations will therefore provide insights into how change in culture may shape the brain, and how the brain may shape the maintenance and transmission of culture across development and across generations. For example, cultural change can occur at either the individual or societal level. As youth move into a new culture, there is a shift in cultural values and beliefs in the process of acculturation (Berry, 1997; Berry, Phinney, Sam, & Vedder, 2006; Sam & Berry 2010). This provides an empirical opportunity to study how youth's brain development is attuned to the new cultural values and beliefs over time, and how brain development may predict change in their adjustment (Chen, Heatherton, & Freeman, 2015). Moreover, cultural change may also occur at the societal level. For example, the cultural meaning of shyness is changing over the past three decades in China: while shyness was related to better social and emotional adjustment in the early 1990s, it became a risk factor for such adjustment in the late 2000s (Chen et al., 2005). Given that youth's brain development is sensitive to the sociocultural environment (e.g., Blakemore & Mills, 2014), it may serve as a key mechanism underlying the change in the association between cultural values and youth's adjustment.

Current Advances in Developmental Cultural Neuroscience

Guided by the framework of developmental cultural neuroscience, research has begun to synthesize previously disconnected fields and take a first step toward a comprehensive understanding of brain development in cultural contexts. These lines of research explore a wide range of topics, including face perception, inhibitory control, risk taking, and family relationships. In the following sections, we summarize emerging research using a developmental cultural neuroscience framework as culture is conceptualized as 1) race and ethnicity, 2) SES, and 3) beliefs, which increase our understanding of the processes connecting culture, social practices, neural development, and adjustment.

Culture as Race/Ethnicity

A common way to characterize culture is race and ethnicity. A number of studies document differences in cognition, emotion, and behavior both across different ethnic groups within the United States and across countries in the world (for reviews, see Betancourt & Lopez, 1993; García Coll et al., 1996; Hill, 2001; Markus & Kitayama, 1991; Mistry et al., 2016; Suárez-Orozco & Suárez-Orozco, 1995; Triandis, 1995). Race and ethnicity, in many cases, can be identified via facial features, such as skin color. Therefore, one topic that has been examined using the developmental cultural neuroscience approach is race perception. It has been well-documented that individuals can differentiate between faces of their own versus other cultures: people are better at perceiving and recognizing facial expressions of individuals from their own culture relative to other cultures, a phenomenon called the other-race-effect or in-group advantage (Elfenbein & Ambady, 2002; Kelly et al., 2007; Scott & Monesson, 2009; Vogel, Monesson, & Scott, 2012). Research in adults examining the other-race-effect has shown that the amygdala demonstrates greater activation to racial outgroups and unfamiliar faces versus racial ingroups and familiar faces (DuBois et al., 1999; Hart et al., 2000; Rule et al., 2010). For example, both American and Japanese adults show a stronger amygdala response to cultural outgroup faces than cultural ingroup faces (Rule et

al., 2010). The amygdala is consistently involved in face perception and emotion processing (e.g., Anderson & Phelps, 2001; Santos, Mier, Kirsch, & Meyer-Lindenberg, 2011; Todd, Evans, Morris, Lewis, & Taylor, 2011), and is a key neural region in detecting emotional salience (e.g., Cunningham & Brosch, 2012; Liberzon, Phan, Decker, & Taylor, 2003), suggesting that the role of the amygdala in detecting facial expressions is evolutionarily important (Hariri, Tessitore, Mattay, Fera, & Weinberger, 2002; Sergerie, Chochol, & Armony, 2008).

Yet, the developmental process underlying the other-race-effect has remained elusive. Experimental research suggests that infants less than 1 year old can already categorize faces by race and are sensitive to ingroup versus outgroup faces in their environment (for a review, see Shutts, 2015). However, it is unclear when and how culture exerts its influences on youth's neurodevelopment of race perception. Using an international adoption design, in which youth who were raised in orphanage care in either East Asia or Eastern Europe as infants and later adopted by families in the United States, provides a unique, natural experiment to measure early deprivation to faces of other cultures (e.g., exclusive exposure to Asian faces or European faces). This method also provides a natural way to quantify the length of early deprivation (i.e., age of adoption) and the timing of exposure to other race faces is known. Deprivation of other-race faces in infancy disrupts recognition of emotion and increases amygdala response to other-race faces (Telzer, Flannery et al., 2013). Importantly, greater length of deprivation (i.e., later age of adoption) is associated with greater amygdala response to other-race faces. This research not only elucidates how changes in cultural environments (e.g., deprivation of other-race faces) influence youth's neural function over time, but also suggests that early postnatal development may represent a sensitive period for neural development of race perception.

In addition to examining differentiation between own- versus other-race faces, research also investigates developmental changes in youth's neural responses to specific races. Notably, culture conveys knowledge and biases about different racial and ethnic groups (e.g., stereotypes of these races). For example, implicit negative stereotypes about African Americans are still evident in American society. Neuroimaging research in American adults has shown that such stereotypes and biases are also reflected in neural activation. For example, both European American and African American adults show greater amygdala response while viewing Black relative to White faces (Lieberman, Hariri, Jarcho, Eisenberger, & Bookheimer, 2005). Taking a developmental cultural neuroscience approach, research has sought to examine when this emerges. Whereas children do not show heightened amygdala response to Black related to White faces, by adolescence, youth show differential amygdala sensitivity to Black faces (Telzer, Humphreys et al., 2013). Thus, neural biases to race emerge during adolescence, reflecting children's increasing internalization of cultural biases. Echoing findings in adults (Lieberman et al., 2005), both White and Black youth show similar developmental trajectories (i.e., increases in adolescence) in amygdala response to Black faces, suggesting that the salience of race and the learned associations about black versus white may be shared across racial groups (Telzer, Humphreys et al., 2013). Importantly, youths' social environment modulates the amygdala response to race, such that youth with greater peer diversity (Telzer, Humphreys et al., 2013) or who are part of a mixed-race team (Guassi Moreira, Van Bavel, & Telzer, 2017)

show an attenuated amygdala response to Black faces, suggesting that greater contact with individuals from diverse backgrounds can reduce the neural salience of race.

Culture as SES

SES or social class is also considered a key form of culture (Cohen & Varnum, 2016; Kraus, Piff, Mendoza-Denton, Rheinschmidt, & Keltner, 2012). Socioeconomic status can be defined in many ways, including objective measures such as family income and parental education (Kachmar, Connolly, Wolf, & Curley, 2019), as well as subjective measures that define how individuals see themselves in relation to others' status (Adler, Epel, Castellazo, & Ickovics, 2000). Social class and hierarchy create cultural identities among upper- and lower-class individuals, which lead to different patterns of thoughts, feelings, and behavior (e.g., Kraus et al., 2012; Snibbe & Markus, 2005; Stephens, Markus, & Phillips, 2014). For example, working-class families often guide children to perceive the world as relatively materially constrained, and children need to develop interdependent selves to help them adjust to the social context and receive material assistance and support from others. In contrast, upper-class families often guide their children to perceive the world as relatively materially unconstrained, and children need to develop independent selves that focus on one's own internal states, goals, motivations, and emotions (Stephens, Markus, & Phillips, 2014). Indeed, decades of research in developmental psychology highlight that SES influences children and adolescents' academic, cognitive, social and emotional adjustment (for reviews, see Duncan & Brooks-Gunn, 1997; McLoyd, 1998; Evans, 2004; Sirin, 2005).

Association between objective measures of SES and brain function.—Attention has been paid to how objective measures of SES (e.g., family income, parents' educational attainment and occupational prestige) influence brain development (for reviews, see Hackman & Farah, 2009; Farah, 2017). Accumulating evidence consistently suggests that objective SES plays a profound role in youths' structural brain development in regions supporting language, reading, memory, executive function, social cognition, and emotional processing (e.g., Hanson et al., 2015; Kim et al., 2013; Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006; Stevens, Lauinger, & Neville, 2009; Tomalski et al., 2013). In addition, objective SES is related to developmental changes in youths' neural function, including differences in brain activity, connectivity, and neural networks (e.g., Duval et al., 2017; Raizada, Richards, Meltzoff, & Kuhl, 2008; Sheridan, Sarsour, Jutte, D'Esposito, & Boyce, 2012). For example, family income and parents' educational attainment predicts adolescents' neural activity during the processing of threatening faces (Muscatell et al., 2012). Specifically, lower SES is associated with greater activity in regions involved in thinking about the minds of others (e.g., dorsomedial prefrontal cortex) as well as regions involved in emotion and threat processing (e.g., amygdala). Similarly, childhood poverty, such as low family income, predicts increased activity in the amygdala and reduced activity in cognitive control regions during emotion regulation among young adults (Kim et al., 2013). Importantly, concurrent income during adulthood is not associated with neural activity, suggesting that childhood SES has a long-term impact on brain development and may not be compensated by later SES during adulthood (Kim et al., 2013). Extending research on objective SES and youth's neural activation, lower family income is associated with reduced connectivity between the hippocampus and amygdala and several neural

regions, which is associated with greater depression, suggesting such changes in neural connectivity related to SES may precede mental illness (Barch et al., 2016). Moreover, in a large community-based study investigating how neighborhood SES influences functional brain network connectivity, the typical age-related increases in local segregation of neural networks is less evident among youth in low-SES neighborhoods compared to those in high-SES neighborhoods (Tooley et al., 2019). Taken together, these findings suggest that SES may not only change normative patterns of neural activation, but also alter neural connectivity in childhood and adolescence.

Association between subjective measures of SES and brain function.— Although most research on SES and brain development relies on objective SES, subjective SES – subjective feelings about one's standing in society relative to others (Goodman et al., 2000, 2001) – also plays a role in youth's neural development. For instance, a recent study measured both objective and subjective SES and examined if each aspect of SES has distinctive contributions to youth's neural processing of race (Muscatell, McCormick, & Telzer, 2018). Although there is no relationship between objective SES and neural response to race, adolescents who perceived themselves as having lower social status in society showed greater activity in neural regions involved in processing salience (e.g., amygdala), deeper perceptual encoding of faces (e.g., fusiform face area), and thinking about the minds of others (e.g., dorsomedial prefrontal cortex, medial prefrontal cortex) when viewing Black faces relative to White faces. These results suggest that race may be more salient for youth with relatively low subjective social status and highlight the unique role of subjective SES in shaping how the brain responds to race. Given that culture is multifaceted, this study is a good example of how different dimensions of culture – race and social class – interact with each other. An exciting line of research suggests that the meanings and impacts of high (vs. low) social status as well as subjective (vs. objective) social status may vary across Western and East Asian countries (e.g., Miyamoto et al., 2018; Park et al., 2013), providing directions for future research examining the impact of social status on the developing brain across cultures.

Culture as Beliefs and Values

Culture is also reflected in the beliefs that parents, teachers, and children hold, which play a profound role, either consciously or unconsciously, in children's development. Stereotypes of adolescence are embedded in culture. For instance, American parents, teachers, and youth tend to view teens as irresponsible, conflictual, rebellious, and disengaged (Buchanan & Holmbeck, 1998; Hines & Paulson, 2006), whereas Chinese youth often view adolescence as a time of fulfilling family and school responsibilities (Qu, Pomerantz, et al., 2016; Qu, Pomerantz, Wang, & Ng, in press). Research is beginning to show that these cultural stereotypes of adolescence may also modulate brain development (Qu et al., 2018). Adolescents who hold negative stereotypes of teens show longitudinal increases over time in ventrolateral prefrontal cortex activation, which is, in turn, associated with longitudinal increases in risk-taking over time. These findings offer initial evidence that negative stereotypes of adolescence, which are culturally shaped, may become self-fulfilling prophecies via changes in neural processing over time. Importantly, these findings underscore that cultural beliefs – in this example stereotypes of adolescence – become

embedded in the developing brain and can impact developmental trajectories of adjustment and well-being.

Summary of Current Developmental Cultural Neuroscience Research

As we reviewed above, advances in developmental cultural neuroscience research so far have provided exciting findings on the role of culture in brain development, which also points to promising directions for future research. First, current research suggests that neural regions involved in several processes and functions, such as face perception, emotion regulation, cognitive control, and perspective taking are influenced by culture in developing youth. It is important to note that there are many other psychological patterns and processes that have yet to be explored. As documented by extant literature in cultural neuroscience research in adults, neural processes underlying other cognitive abilities or social functions (e.g., self-construal and attribution) differs across cultures (e.g., Han & Humphreys, 2016; Kitayama et al., 2018; Mason & Morris, 2010). Therefore, it is important to call for more research in developmental cultural neuroscience, so that we can fully understand how brain regions are culturally shaped across development.

Second, given developmental cultural neuroscience is still in its nascent stage, it is too early to draw conclusions about the overall pattern for psychological and neural mechanisms by which cultural shaping occurs. It is possible that some neural regions may be particularly sensitive to culture, as they are shaped by environmental input during sensitive periods of development, suggesting that culture may play an outsized role during developmentally plastic periods. For example, prior research suggests that amygdala activation is shaped by cultural input, especially early in development, which has long-term consequences in later neural processes (Telzer, Flannery et al., 2013). As more studies accumulate, researchers will be able to summarize what psychological and neural processes are culturally-general and culturally-sensitive across the lifespan, which will provide important insights into understanding the role of culture in neuroplasticity.

Third, in addition to using an fMRI approach, future research should take advantage of the diverse tools in neuroscience and employ a variety of neuroimaging methods (e.g., EEG, functional near-infrared spectroscopy, structural MRI, and diffusion tensor imaging) to unpack the role of culture in brain development at different levels (e.g., brain function, brain structure, and neural connectivity). Moreover, accompanied by observation, surveys, experience sampling methods (e.g., daily diaries), experimental designs, and physiological assessments, this line of research can shed light on how culture plays a role in brain development via social contexts and how such culturally shaped neural processes have implications in children and adolescents' adjustment in daily life.

Guidelines for Conducting Developmental Cultural Neuroscience Research

Research in developmental cognitive neuroscience has grown considerably – from a few hundred publications in the year 2000 to over 1400 publications in the year 2010 (Blakemore, 2012). As the field continues to grow, it is important to provide guidelines for future research, even for those whose research does not focus on culture. Below we outline five guidelines for better incorporating culture into developmental neuroimaging research.

(1) Provide detailed information to characterize the sample

As we review, the majority of studies do not report detailed cultural information such as ethnicity or SES information that is crucial for advancing our understanding of normative human development. We propose key information that should be reported in any publication (Table 2). Although any single study may not be able to examine cultural differences in youth's neural processes due to small sample size, providing such information will make it possible for future meta-analyses to examine this issue across multiple studies. Moreover, collecting information on participants' cultural background and socioeconomic status is not only important for future research aimed at directly examining cultural differences in brain development, but also useful for studies aimed at understanding population-level effects that generalize across samples. For example, controlling for culture-related variables or weighting the sample of cultural composition to make it more representative (e.g., LeWinn et al., 2017) allows researchers to examine cultural similarity or general patterns across populations. Finally, we recommend that researchers in the future be clearer about whether certain effects are based upon specific groups or are generalizable to the population or across the globe.

(2) Recruit diverse cultural groups

Not only should researchers provide more detailed reports of their samples, it is also theoretically and empirically important to actively and purposefully broaden the diversity of study samples. We encourage researchers to recruit participants across different countries and societies around the world, as well as across different ethnicities, regions (e.g., rural versus urban), and socioeconomic groups within the same country. By recruiting diverse cultural groups, we can elucidate whether, how, and why brain development and its association with psychological and behavioral adjustment vary across cultures. Recent advances in neuroscience have minimized cross-site variation (i.e., differences in data due to different scanners) in fMRI data (Parrish et al., 2000; Friedman & Glover, 2006; Friedman et al., 2008), making it more feasible to recruit children and adolescents in different cultures. Of course, access to MRI scanners is limited in many regions around the world, but efforts are in place to build capacity for brain research in low- and middle-income countries (e.g., Fogarty International Center).

(3) Make use of both convenience and large-scale samples

In developmental cultural neuroscience, both convenience and large-scale samples have important uses, and it is vital that researchers utilize samples that best meet their specific research questions. For example, any study that aims to understand general developmental processes should utilize samples that are representative of the population of interest. Not only do these studies have enough statistical power to compare cultural groups, but they also are much more likely to generalize across the population. Despite the strengths of these types of studies, they are very costly and require large teams with diverse expertise, which are not available to all researchers. Furthermore, measures are often inherently less adaptable to specific cultures and these psychological constructs need to be common and accessible to most participants. Therefore, researchers may be unable to examine cultural processes using detailed and in-depth measures and assessment.

Given such economical and empirical concerns, it is also crucial to highlight the value of convenience or more targeted samples (Jager, Putnick, & Bornstein, 2017) that allow researchers to use culturally specific tasks, a key guideline that we elaborate below in #5. Indeed, homogeneous convenience samples that recruit participants using specific cultural criteria can examine cultural values and processes specific to that group. Such approaches will provide narrow but unique understanding of youth development in specific cultural groups with clearer generalizability compared to conventional convenience samples (Jager et al., 2017). In summary, researchers should carefully consider the strengths and weaknesses of sampling techniques in reference to their specific research questions, understanding that both large-scale and convenience samples are useful in developmental cultural neuroscience.

(4) Employ a combination of cross-sectional and longitudinal designs

To better examine the role of culture in youths' neurodevelopment, researchers need to employ both cross-sectional and longitudinal neuroimaging designs. Cross-sectional designs can provide an important snapshot of age differences in neural processes underlying cognitive, social, and emotional functioning, but also have limitations that may yield misleading conclusions about developmental processes (Grimm, Davoudzadeh, & Ram, 2017; Kraemer, Yesavage, Taylor, & Kupfer, 2000). For example, although children in two cultures may show the same neural activation at the mean level based on cross-sectional designs, children in one culture may be in the upward trajectories and children in the other culture may be in the downward trajectories. Such differences would not be observable in children's mean-level activation at a single time point. Therefore, many scholars highlight the importance of applying longitudinal designs in developmental neuroscience and provide guidelines for such practices (e.g., Dahl, 2011; Telzer, McCormick, Peters, Cosme, Pfeifer, & van Duijvenvoorde, 2018). These designs are better able to assess key aspects of the developmental cultural neuroscience framework, including general adolescent brain development (e.g., Braams et al., 2015; Pfeifer et al., 2011; Qu et al., 2015), the influence of culture on brain development and its associations with youth adjustment, as well as reciprocal relationships between neurodevelopment, the cultural environment, and adjustment.

(5) Design culturally relevant tasks that capture culture-specific values and practices

Given that developmental cultural neuroscience aims to examine the role of culture in youth's neural development, key to this endeavor is to design culturally relevant tasks that capture unique cultural values and practices. When designing these tasks, it is important to consider two issues. First, the usefulness of a task paradigm depends on whether it captures the cultural values and practices that researchers aim to examine. Therefore, it is essential to identify the psychological process informed by past literature in cultural or developmental psychology, and then accordingly to design a task to measure the neural mechanisms underlying that process. Second, as we study youth in different cultures, tasks need to be culturally comparable. Cross-cultural work in developmental psychology explicitly tests for measurement equivalence in self-report measures across cultures, which ensures that the same psychological construct is measured across different cultural groups (e.g., participants use the same scale in the same manner). The practice and emphasis on cultural equivalence of measurement should also be applied in developmental cultural neuroscience research in

which researchers develop tasks that participants from different cultures use in the same manner, ensuring that the cultural comparisons are meaningful.

Key Contributions of Developmental Cultural Neuroscience

Developmental cultural neuroscience represents an integrative approach to examine neural mechanisms underlying cultural differences and similarities in psychological processes across development. Advances in developmental cultural neuroscience will provide promising theoretical and applied implications, including but not limited to the following three key contributions.

(1) Broaden the understanding of cultural transmission

The developmental cultural neuroscience framework provides a holistic perspective on how culture influences child development. Instead of treating cultural influence as static, this approach captures the dynamic process of cultural transmission. Prior developmental research has revealed the role of culture in shaping youth's trajectories at the psychological and behavioral level (e.g., Chen, 2018; Greenfield & Suzuki, 1998; Rogoff, 2003). Developmental cultural neuroscience research will not only provide insights into how culture shapes child development at the neural level, but also will delineate how neurodevelopment interacts with psychological and behavioral adjustment across different cultural contexts. Youths' neurodevelopment may serve as a key mechanism through which culturally rooted social practices contribute to divergent trajectories in academic, cognitive, social, and emotional development. Thus, youths' brain development provides a window to examine how culture influences their beliefs, feelings, and behaviors. By examining youths' neural development, we can elucidate some of the processes through which cultural values are transmitted from the social environment to children across generations. Moreover, this research can help us better understand when, how, and why there are cultural differences in youths' adjustment over the course of development. In addition to depicting different trajectories of brain development across cultures, developmental cultural neuroscience can help us identify key social practices that contribute to such differences in neural development, providing empirical explanations for cultural differences in child functioning.

(2) Provide insights into neuroplasticity

The brain is highly plastic and sensitive to the social environment and engagement in cultural practices. For example, neuroimaging research has documented how unique experience leads to variations in brain structure and function among musicians, taxi drivers, and jugglers (Draganski et al., 2004; Maguire et al., 2000; Münte, Altenmüller, & Jäncke, 2002). With a focus on culture, developmental cultural neuroscience can provide evidence on how culturally rooted social practices contribute to changes in brain structure and function. Cultural psychology has demonstrated that East Asians are more interdependent or less independent in their social orientation compared to European Americans (Markus & Kitayama 1991). Consistent with this distinction, American adults, especially young adults, have greater grey matter volume and thickness of the orbitofrontal cortex and medial prefrontal cortex compared to their East Asian counterparts (e.g., Chee et al., 2011; Yu et al., 2019), and the number of years spent in the U.S. predicts increased gray matter volume

in the orbitofrontal cortex among East Asians who are genetically more sensitive to cultural influences (i.e., carrying the 7- or 2-repeat allele of the dopamine D4 receptor gene) (Yu et al., 2019). Therefore, exposure to a new culture may guide neural plasticity in a culturally specific way over the lifespan.

(3) Provide important implications for youth's learning and psychological adjustment

An advantage of developmental cultural neuroscience is the ability to identify key cultural resources that help to promote youth's positive development. As an interdisciplinary approach, this framework can provide empirical evidence at behavioral, psychological, and neural levels to examine whether a specific social practice has positive implications for youth's adjustment. For example, in order to reduce heightened risk taking among some cultural groups, there is great need for systematic research that examines cultural resources. Using a developmental cultural neuroscience approach, we identified a meaningful cultural resource – family obligation – in reducing Latin American adolescents' real-life risk taking via modulating reward-related processing in the brain (Telzer, Fuligni et al., 2013a, 2013b). Moreover, as a growing number of interventions aim to promote minority and underserved youth's achievement (Destin, 2020; Yeager & Walton, 2011; Yeager et al., 2016), researchers highlight the importance of incorporating neurobiology in closing racial and ethnic disparities in school readiness and academic achievement (Levy, Heissel, Richeson, & Adam, 2016; Noble, Tottenham, & Casey, 2005). Moving beyond prior research that solely focuses on youth's behavior, developmental cultural neuroscience equips us with valuable tools to examine the underlying neural mechanisms by which social environments and practices shape child development.

Conclusion

Progress in neuroimaging for the study of human brain structure and function *in vivo* has provided groundbreaking understanding of brain development across the lifespan. Despite such success, we call attention to the importance of incorporating culture into the empirical investigation of neurodevelopment. Our analyses based on studies included in recent meta-analyses suggest that prior developmental cognitive neuroscience research tends to both under-report cultural demographic information and utilize culturally homogenous samples. To fully address this issue, we propose an emerging interdisciplinary approach – developmental cultural neuroscience – aiming to examine the role of culture in youth's brain, psychological, and behavioral development. Equipped by theories and tools from developmental psychology, cultural psychology, and neuroscience, this interdisciplinary approach will provide both theoretical and practical implications – it will not only increase our understanding of youth's brain development under divergent cultural circumstances, but will also provide the foundation for future interventions that target culturally diverse youth.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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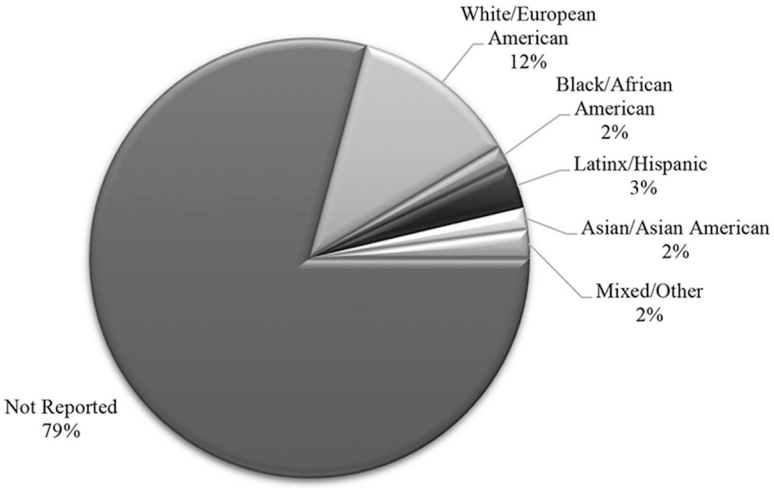

Figure 1.

Racial/ethnic background of research participants, including those not reported. Percentages are based on N=3704 participants.

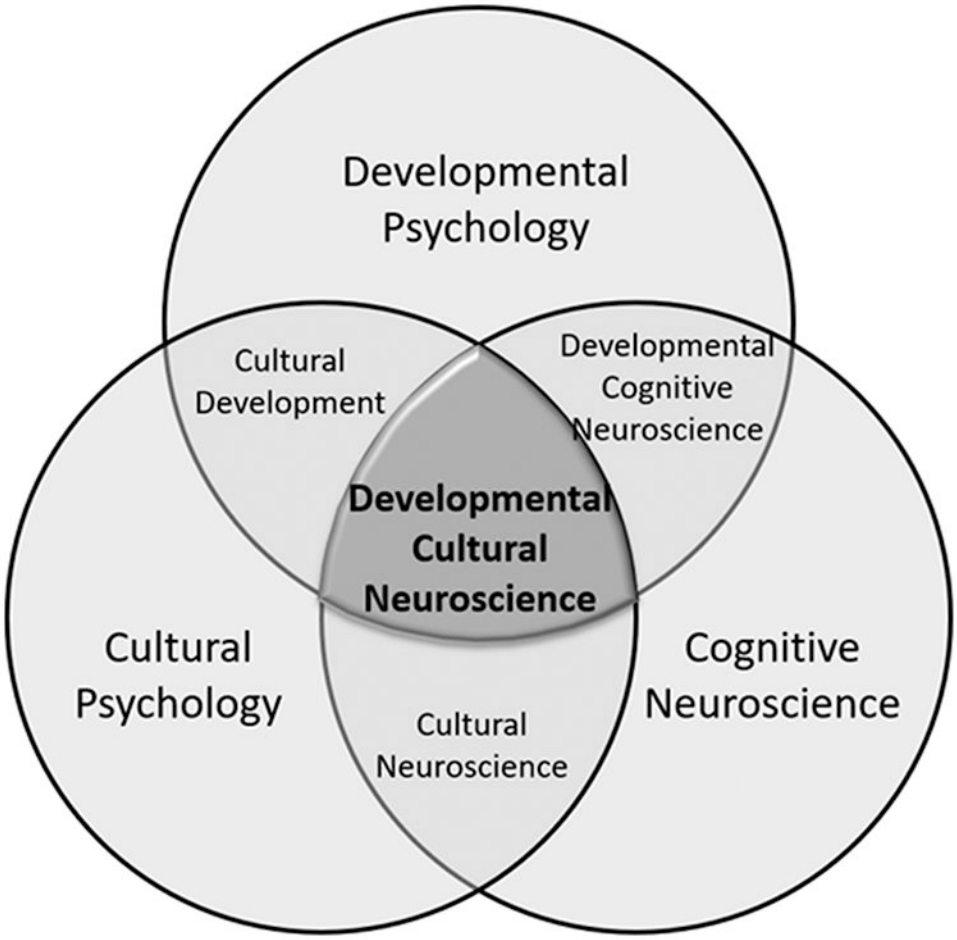

Figure 2.
Developmental cultural neuroscience as an emerging interdisciplinary approach that combines methods from developmental psychology, cultural psychology, and cognitive neuroscience.

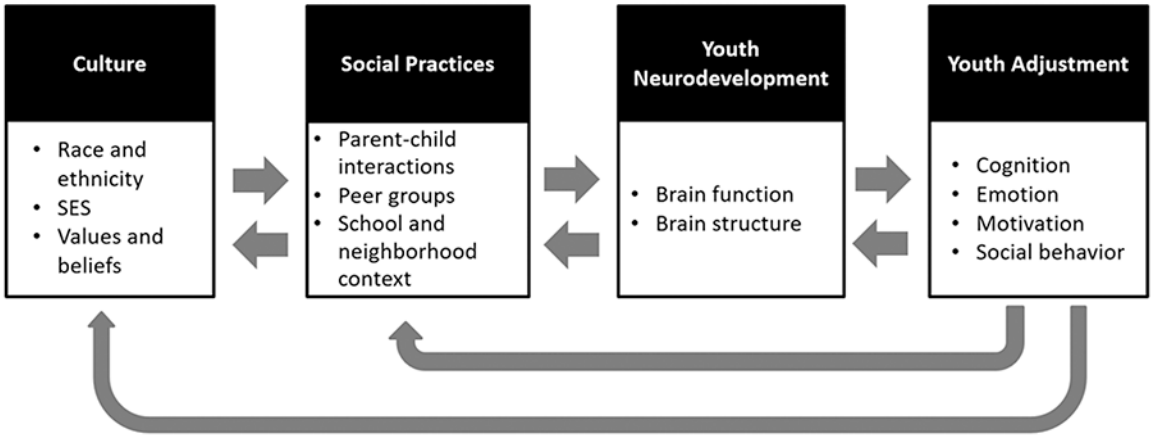

Figure 3.
A developmental cultural neuroscience framework.

Table 1.

Summary of reported demographics in reviewed studies

	N (%)
Geographic Location	
Western samples	79 (99%)
US samples	52 (65%)
Race/Ethnicity	
Detailed Report	18 (22%)
Incomplete Report	4 (5%)
No Report	58 (73%)
SES	
Detailed Report	14 (18%)
Incomplete Report	5 (6%)
No Report	61 (76%)

Note. Percentages are based on N=80 studies.

Table 2.

Checklist of key demographic information to collect and report.

Essential Information	**Reason**	**Guidelines**
Sex	Understanding biological sex.	Include biological sex (male/female).
Age	Understanding development.	Include age (mean and range).
Race and Ethnicity	Understanding cultural influences and generalizability.	Include number/percentage of participants from each ethnicity/pan-ethnicity (e.g., Asian-American) and specific country, culture, or race (e.g., Chinese).
Objective SES	Understanding cultural influences and generalizability.	Include measures such as family income, income to needs ratio, parental education, etc.
Recommended Information	**Reason**	**Recommendations**
Immigrant Status	Understanding multicultural influences in youth's lives.	First- second- or third+ generation; years in the host country.
Cultural Orientation	Addressing acculturation.	Measures of orientation toward host and native cultures.
Cultural Values	Measuring processes underlying cultural influences on development.	Interdependent vs. independent values; collectivism vs. independence; etc.
Subjective SES	Understanding cultural influences associated with social standing.	Perceived social standing relative to others at neighborhood and country-levels.

Note. Essential information is suggested for all developmental neuroscience research to report regardless of whether or not the researchers are interested in culture. Recommended information is intended for those wishing to examine culture more deeply.