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Neural processes underlying cultural differences in cognitive persistence

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ABSTRACT

Self-improvement motivation, which occurs when individuals seek to improve upon their competence by gaining new knowledge and improving upon their skills, is critical for cognitive, social, and educational adjustment. While many studies have delineated the neural mechanisms supporting extrinsic motivation induced by monetary rewards, less work has examined the neural processes that support intrinsically motivated behaviors, such as self-improvement motivation. Because cultural groups traditionally vary in terms of their self-improvement motivation, we examined cultural differences in the behavioral and neural processes underlying motivated behaviors during cognitive persistence in the absence of extrinsic rewards. In Study 1, 71 American (47 females, M=19.68 years) and 68 Chinese (38 females, M=19.37 years) students completed a behavioral cognitive control task that required cognitive persistence across time. In Study 2, 14 American and 15 Chinese students completed the same cognitive persistence task during an fMRI scan. Across both studies, American students showed significant declines in cognitive performance across time, whereas Chinese participants demonstrated effective cognitive persistence. These behavioral effects were explained by cultural differences in self-improvement motivation and paralleled by increasing activation and functional coupling between the inferior frontal gyrus (IFG) and ventral striatum (VS) across the task among Chinese participants, neural activation and coupling that remained low in American participants. These findings suggest a potential neural mechanism by which the VS and IFG work in concert to promote cognitive persistence in the absence of extrinsic rewards. Thus, frontostriatal circuitry may be a neurobiological signal representing intrinsic motivation for self-improvement that serves an adaptive function, increasing Chinese students' motivation to engage in cognitive persistence.

Introduction

Motivation is perhaps the most important construct in the educational and workforce systems. A distinction has been drawn between internal (or intrinsic) and external (or extrinsic) motivation. Intrinsic motivation refers to doing something because it is inherently interesting or enjoyable irrespective of the outcome. Such motivated behaviors, while no doubt adaptive to the organism, are not done for instrumental reasons, but instead for the positive experience associated with extending oneself (Ryan and Deci, 2000). For instance, individuals may engage in a challenging task for the inherently rewarding nature of improving upon their skills. Self-improvement motivation, which occurs when individuals seek to improve upon their competence by gaining new knowledge and improving upon their skills, is critical for cognitive, social, and educational adjustment. In contrast, extrinsic motivation is driven by the outcome or external factors and has a negative impact on enjoyment and future motivation (Deci et al., 1991). For instance, extrinsic rewards (Deci et al., 1999), threats (Deci and Cascio, 1972), or competitive pressure (Reeve and Deci, 1996) diminish interest, enjoyment, and internal motivation (Ryan and Deci, 2000).

While many studies have delineated the neural mechanisms supporting extrinsically motivated behaviors, such as those induced by monetary rewards (e.g., Delgado et al., 2000, 2003; Elliott et al., 2004; Kirsch et al., 2003; Knutson et al., 2000; Geier et al., 2009, 2012; Geier et al., 2010; Padmanabhan et al., 2011; Murayama et al., 2010), less work has examined the neural processes that support intrinsically motivated behaviors. Developmental work has shown that adolescents show improved cognitive control when they are rewarded for doing so (Geier et al., 2009, 2012; Geier et al., 2010; Padmanabhan et al., 2011) and exhibit increased activation compared to children and adults in the ventral striatum when their efforts are extrinsically rewarded (Padmanabhan et al., 2011). Yet, incentivizing individuals with money or other extrinsic rewards can undermine intrinsic motivation (Deci

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et al., 1999; Murayama et al., 2010) and result in negative long-term effects on future motivation (Gneezy et al., 2011). Thus, our goal was to examine the behavioral and neural correlates of motivated behaviors in the absence of extrinsic rewards. Moreover, because cultural groups traditionally vary in terms of their self-improvement motivation, we examined cultural differences in the behavioral and neural processes underlying motivation and cognitive persistence.

The maintenance and enhancement of self-improvement motivation requires a rearing environment that supports and values motivated behaviors, as motivation can be disrupted by unsupportive conditions (Ryan and Deci, 2000). Thus, the social and cultural context can either promote or undermine the natural tendency to extend and exercise one's capacities (Ryan and Deci, 2000). Cross-cultural research has found that individuals from collectivistic cultures (e.g., East Asians) tend to be more intrinsically motivated in academics than more individualistic individuals (e.g., Americans). Recent meta-analyses have revealed consistently high self-improvement motivation in East Asian populations (Heine and Hamamura, 2007), although research has also shown these patterns in other collectivitistic cultures such as Chileans (Heine and Raineri, 2009). Such heightened self-improvement motivation likely arises due to rearing environments that differentially value motivated behaviors. For instance, persistence is highly valued throughout the educational process in many East Asian countries. In Japanese, the term *gambaru* means to persevere through tough times and to do more than one's best to succeed (Binco, 1992) and in China, Confucian teaching emphasizes the exertion of effort in the learning process, which is seen as a moral endeavor and a lifelong task to improve oneself (Chao and Tseng, 2002; Heine et al., 2001; Li, 2004). Shortcuts are looked down upon as persistence to attain a goal is valued and encouraged (Binco, 1992). Moreover, the Chinese notion of *guan,* which means to govern and to love, is evident in parenting practices, including *chiao shun* (training) of children, which characterizes parents' monitoring and correcting children's behavior to ensure they exert effort to do well in school (Chao, 1994). Indeed, Chinese mothers place greater emphasis on their children achieving and improving themselves than do American mothers (Qu, Pomerantz, and Deng, 2016). Finally, the preschool setting in China encourages and values strong cognitive control skills (Tobin et al., 1989), opportunities that are not necessarily provided by or valued in American schools and families (Sabbagh et al., 2006). Thus, collectivitistic cultures socialize children to inherently value self-improvement and to persist in challenging tasks, whereas in American culture, there is a relative lack of persistence and a greater tendency to give up in the face of challenge (Binco, 1992; Heine and Raineri, 2009).

Frontostriatal circuitry is involved in motivated behaviors and effective cognitive control (Casey et al., 2011). The ability to persevere through difficult challenges relies on the lateral prefrontal cortex (PFC). The PFC supports the ability to select and motivate thoughts and actions in relation to internal goals (Kouneiher, Charron, and Koechlin, 2009). In both humans and primates, the inferior frontal gyrus (IFG) is involved in regulation, inhibitory control, and cognitive flexibility (Aron, Robbins, and Poldrack, 2004; Levy and Wagner, 2011; Brass et al., 2005; Neubert et al., 2014; Egner, 2011), and is the center for preparatory responses to engage in effective cognitive control to achieve goals (Matsumoto et al., 2003; Bunge, 2004). Individuals who are not motivated to engage in challenging tasks show decreases in IFG activation over time (Murayama et al., 2010), and adults with poor delay of gratification measured prospectively in childhood show lower IFG activation during cognitive control (Casey et al., 2011), underscoring the important role of the IFG in promoting motivated behaviors.

In addition to the IFG, the mesolimbic reward system supports motivated behaviors. The positive experience associated with extending oneself promotes enjoyment and spontaneous self-satisfaction (Ryan and Deci, 2000). Thus, the ventral striatum (VS), which responds to rewards and is tightly tied to motivated behavior in both humans and animals (Knutson and Cooper, 2005; Spear, 2011; Pessiglione et al., 2006; Ikemoto and Panskepp, 1999; Delgado, 2007) is likely linked to the rewarding nature of self-improvement. Indeed, ventral striatum activation during challenging tasks promotes more effective working memory, (Satterthwaite et al., 2012), and is associated with intrinsic motivation (Murayama et al., 2010), suggesting that ventral striatal responses during challenging cognitive control tasks may reflect intrinsic reinforcement signals.

In the current study, we recruited two samples of students, Chinese and Americans, who traditionally vary in terms of their self-improvement motivation. In Study 1, we examined cultural differences in self-improvement motivation and cognitive persistence. Participants completed a cognitive control task that required effort and persistence with no reinforcements or rewards. Cognitive persistence was measured by examining change in performance across the task. East Asian culture socializes children to engage in self-improvement and persist in challenging tasks, whereas in American culture, there is a relative lack of persistence and a greater tendency to give up when performing difficult tasks (Binco, 1992). Indeed, prior work has shown that East Asian students are more likely to persist following failure compared to their American counterparts (Heine et al., 2001). We therefore hypothesized that Chinese students would show greater cognitive persistence, and this would be explained by their increased motivation for self-improvement.

In Study 2, we examined the neural processes that explain cultural differences in cognitive persistence. Because individuals who are not motivated to engage in challenging tasks show decreases in IFG activation over time (Murayama et al., 2010), we hypothesized that Chinese students' increased motivation to engage in self-improvement would rely on increasing engagement of the IFG, suggesting increasing effort and persistence. In addition, because persistence and self-improvement are highly valued in East Asian culture, and effort is seen as a moral endeavor (Chao and Tseng, 2002; Heine et al., 2001; Li, 2004), we hypothesized that Chinese students would evidence increasing ventral striatum activation over time, ventral striatum activation that would remain low in American students across the task. Finally, the ventral striatum may be functionally connected to the IFG through bottom-up processing that facilitates cognitive engagement. Thus, in addition to examining neural reactivity in the IFG and ventral striatum, we examined functional coupling between these regions in order to test whether reward processes facilitate effective cognitive engagement. We hypothesized that Chinese students' increased self-improvement motivation may be subserved through reward processes that shape their motivation to engage in cognitive control. Thus, Chinese students would show increasing functional coupling between the striatum and IFG across the task, functional coupling that would promote more effective cognitive persistence.

Study 1 methods

Participants

Participants included 71 American (47 females, M=19.68 years) and 68 Chinese (38 females, M=19.37 years) students. All American participants were born and raised in the United States and were of European decent. All Chinese participants were born and raised in China, had lived in China for at least 18 years, and came to United States for college. Participants were matched in terms of age and level of education. Participants provided written consent in accordance with the University of Illinois' Institutional Review Board.

Cognitive persistence task

Participants completed several rounds of a Go-NoGo (GNG) Task to target cognitive persistence. Participants were presented with a series of rapid trials (500 ms), each displaying a single letter, and were

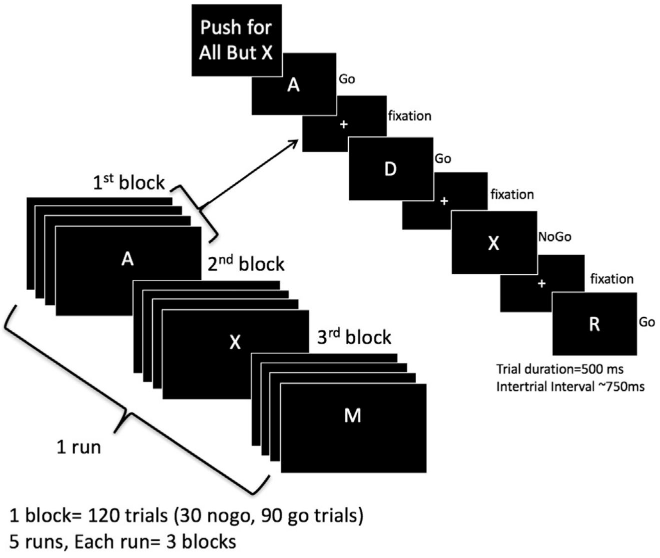

Fig. 1. Go Nogo Task.

instructed to respond with a button press as quickly as possible to all letters except for X. The X occurred on 25% of trials. Thus, participants developed a pre-potent response to press (go) upon stimulus onset, but must inhibit the go response on X trials (no-go). Each 500 ms trial was separated by a fixation, which was jittered according to a random gamma distribution (M=1000 ms). Participants completed 5 runs of the task, and each run of the task included 3 blocks of 40 trials. Each of the 5 runs of the task was separated by a two-minute rest period (Fig. 1).

Performance on the task was measured via false alarm rate (i.e., pressing on no-go trials), such that a higher percent of false alarms is indicative of poorer performance. Our primary analysis examined changes in behavioral performance across the first, second, and third blocks of the task. Declines in cognitive persistence would be represented by increases in false alarms across the blocks, whereas effective cognitive persistence would be represented by either no change or even a decrease in false alarms across the blocks.

Self-improvement motivation

To test whether self-improvement motivation explains cultural differences in cognitive persistence, participants rated two items to indicate how important (1= *not important at all*, 5= *very important*) it is to “Improve myself much of the time” and “Believe that I should always try to improve my abilities.” The two items were averaged, with higher numbers indicating greater self-improvement motivation (α=.91).

Results

Cultural differences in cognitive persistence

We conducted a 2 (group: Chinese, American) x 3 (task block: 1st, 2nd, 3rd) way ANOVA to examine cultural differences in cognitive persistence across the task. Results indicated a significant interaction, *F*(2274)=4.05, *p*=.02. To probe the interaction, we conducted *post hoc* independent samples *t*-tests to compare performance within each block of the task across cultural groups. Chinese (20.74% false alarms) and American (24.54% false alarms) students only marginally differ in false alarm rate on the first third of the task (*t*(137)=1.93, *p*=.06), but American participants' performance levels declined over time to a greater extent than did Chinese participants, such that by the third block of the task, Chinese students (23.32% false alarms) had significantly fewer false alarms than did American students (31.24% false alarms; *t*(137)=3.11, *p*=.002), suggesting that Chinese students more effectively engage in cognitive persistence.

The mediating role of self-improvement motivation

We further examined whether American and Chinese participants differ in their self-improvement motivation. American participants reported significantly lower self-improvement motivation (*M*=4.27, *SD*=.70) than did their Chinese counterparts (*M*=4.65, *SD*=.59), *t*(137)=3.44, *p*=.001. We conducted mediation analyses to examine whether self-improvement motivation mediates cultural differences in cognitive persistence. To represent change in cognitive persistence over time, we computed a difference score of false alarms between the first and last block of the task, such that lower scores indicate greater declines in false alarms (i.e., improved performance). With this index, and consistent with the findings reported above, we found a significant cultural difference in change of performance over time (*t*(137)=2.68, *p* < .01), such that American students' performance on the task declined significantly more than did Chinese students'. Bias-corrected bootstrapping resampling techniques were used to test the indirect effect with self-improvement motivation as the mediator (Preacher and Hayes, 2008). Using 1000 bootstrap resamples, results indicated that self-improvement motivation accounts for the effect of culture on change in cognitive performance, (indirect effect: b=−.06, SE=.03, 95% CI: [−.13, −.02]; see Fig. 2). After taking into account self-improvement motivation, the cultural difference in cognitive persistence was no longer significant, with a 27% reduction in the total effect.

Discussion

Results of Study 1 show that Chinese students engaged in greater persistence on a cognitive control task than their American counterparts. These findings are consistent with prior work showing that East Asian individuals perform significantly better on cognitive control, executive functioning, and behavioral inhibition tasks (Sabbagh et al., 2006; Lan et al., 2011), with such cultural differences emerging as early as two-years of age (Sun, 2011; Gartstein et al., 2006). Our mediation analyses suggest that cultural differences in self-improvement motivation explain such cultural differences in cognitive persistence. In particular, Chinese students scored significantly higher on their motivation to improve upon their abilities, and such heightened motivation was associated with greater cognitive persistence during cognitive control. East Asian culture reinforces effort in the learning process, sees the utility of effort in promoting self-improvement and facilitating achievement, and considers effort a moral endeavor (Chao and Tseng, 2002; Heine et al., 2001; Li, 2004). American parents and teachers, on the other hand, often attribute academic competence to ability rather than effort (Stevenson et al., 1990; Hess et al., 1987), and so American students are less likely to persevere and engage in self-improvement. Results of this behavioral study show that Chinese students engage in greater cognitive persistence in the absence of reinforcements or rewards, and such heightened persistence is explained by Chinese students' desire for self-improvement. Our findings suggest that socializing youth to believe in self-improvement and the

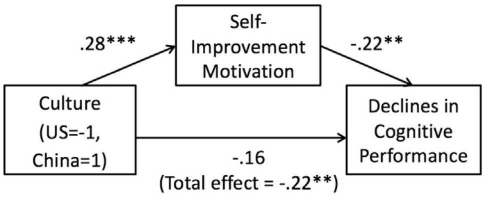

Fig. 2. Self-improvement motivation mediates cultural differences in cognitive persistence on the Go-Nogo Task. ** *p* < .01, *** *p* < .001.

value of effort can have significant implications for their motivation and cognitive persistence.

After establishing that self-improvement motivation explains cultural differences in cognitive persistence, Study 2 sought to examine the neural processes underlying such cultural differences.

Study 2 methods

Participants

Participants included 14 American (7 females, *M*=19.02 years) and 15 Chinese (7 females, *M*=19.38 years) students. All American participants were born and raised in the United States and were of European decent. All Chinese participants were born and raised in China, had lived in China for at least 18 years, and had been living in the United States for less than one year. Participants were matched in terms of age and level of education. Participants completed the identical Go-NoGo Task used in Study 1 during an fMRI scan. Participants provided written consent in accordance with the University of Illinois' Institutional Review Board.

fMRI data acquisition and analysis

All imaging data were collected using a 3.0-Tesla Siemens Trio MRI scanner. Functional scans included T2*-weighted echoplanar images (EPI) [slice thickness=3 mm; 38 slices; gap=1 mm, TR=2000 ms; TE=25 ms; matrix=92×92; field of view=230 mm; voxel size 2.5×2.5×3mm^3]. Structural scans consisted of a T2*weighted matched-bandwidth (MBW) high-resolution anatomical scan (TR=4000 ms; TE=64 ms; field of view=230; matrix=192×192; slice thickness=3 mm; 38 slices) and a T1* magnetization-prepared rapid-acquisition gradient echo (MPRAGE; TR=1900 ms; TE=23 ms; field of view=230; matrix=256×256; sagittal plane; slice thickness=1 mm; 192 slices). The orientation for the MBW and EPI scans was oblique axial to maximize brain coverage.

Functional data were analyzed using SPM8 (Wellcome Department of Cognitive Neurology, London, UK). Within each functional run, image volumes were realigned to correct for head motion (no participant exceeded 1 mm of maximum image-to-image motion in any direction), segmented by tissue type (cerebrospinal fluid, grey matter, and white matter), normalized into standard MNI stereotactic space (resampled at 3×3×3 mm), and smoothed with an 8 mm Gaussian kernel, FWHM.

Statistical analyses were performed using the general linear model in SPM8. Each trial was convolved with the canonical (double-gamma) hemodynamic response function. The task was modeled as an event-related design, with the duration of each trial lasting 500 ms. Null events, consisting of the jittered inter-trial intervals were not explicitly modeled and therefore constituted an implicit baseline. The following conditions were included in the fixed effects, first level model: go trials, no-go trials, and false alarms. A parametric modulator was included, in which we weighted the trials according to the block, such that trials occurring in the first third were weighted with a 0, trials occurring in the second third were weighted with a 1, and trials occurring in the final third were weighted with a 2. By modeling the parametric regressor, we were able to examine activation that increased or decreased linearly as a function of the task blocks. The time series was high-pass filtered using a cutoff of 128 s and serial autocorrelations were modeled as an AR(1) process. Contrast images were averaged across runs for each participant, and entered into a random effects analysis at the group level.

To examine functional coupling between the ventral striatum and IFG, we conducted psychophysiological interaction (PPI) analyses (Friston, Buechel, Fink, Morris, Rolls, and Dolan, 1997). We used the ventral striatum as the seed region, which was defined structurally using the WFUpickatlas (Maldjian, Laurienti, Kraft, and Burdette, 2003; Tzourio-Mazoyer et al., 2002). PPI analyses were run using a generalized form of the context-dependent psychophysiological interaction in which the automated gPPI toolbox in SPM (gPPI; McLaren, Ries, Xu, and Johnson, 2012) was used to 1) extract the deconvolved times series from the ventral striatum ROI for each participant to create the physiological variables; 2) convolve each trial type with the canonical HRF, creating the psychological regressor; and 3) multiply the time series from the psychological regressors with the physiological variable to create the PPI interaction terms. This interaction term identified regions that covaried in a task-dependent manner with the ventral striatum. For the first level model, one regressor representing the deconvolved BOLD signal was included alongside each psychological and PPI interaction terms for each condition type to create a gPPI model.

To correct for multiple comparisons, we conducted a Monte Carlo simulation implemented using 3dClustSim in the software package AFNI (Ward, 2000) to determine an appropriate cluster-size threshold given the empirical smoothness of the images to ensure overall false discovery rate (FDR) of less than .05. Results of the simulation indicated a voxel-wise threshold of $p < .005$ combined with a minimum cluster size of 87 voxels for the whole brain. Results using a more liberal threshold of $p < .005$ and 40 contiguous voxels are also included to guard against Type II errors (cf. Lieberman and Cunningham, 2009). Results that survive FDR correction are noted with an asterisk in the Tables.

Results

Behavioral results

Cultural differences in cognitive persistence

We conducted a 2 (group: Chinese, American) x 3 (task block: 1st, 2nd, 3rd) way ANOVA to examine cultural differences in cognitive performance across the task blocks. Results indicated a significant interaction, $F(2,54)=14.26$, $p < .001$. To probe the interaction, we conducted *post hoc* repeated measures analyses within each cultural group (i.e., to compare performance across the task within each group) and independent samples *t*-tests (i.e., to compare performance within each block of the task across cultural groups). As shown in Fig. 3, Chinese and American students did not differ in false alarm rate on the first third of the task ($t(27)=.37$, ns), but Chinese participants' performance significantly improved over time ($F(2,28)=5.3$, $p < .05$), whereas American participants' performance significantly declined ($F(2,26)=4.7$, $p < .05$), such that by the third block of the task, Chinese students had significantly fewer false alarms than American students ($t(27)=2.3$, $p < .05$). These findings replicate the effects found in Study 1.

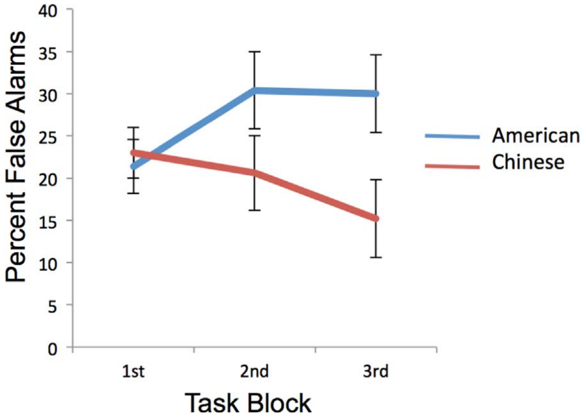

Fig. 3. Percent false alarms across the task blocks for Chinese and American participants.

Table 1
Cultural differences in neural regions which showed linear increases in functional reactivity as a function of task block.

Anatomical Region	BA	x	y	z	t	*k*
Chinese > American, Go Trials						
IFG	45	51	23	10	3.16	110*
Ventral striatum		21	11	−2	3.77	104*
Insula		−30	14	7	3.55	145*
Cingulate		12	−19	31	4.31	135*
STS		54	−22	−5	4.05	94*
Cuneus		22	−86	7	5.04	134*
Fusiform gyrus		−39	−49	−17	4.06	48
Insula		36	20	−14	4.52	52
Putamen		−21	3	13	4.85	61
DLPFC	46	45	41	16	3.70	49
VLPFC	10	30	65	4	3.72	71
IFG	45	56	11	24	3.91	59
DMPFC	10	20	44	24	3.83	47
MFG	8	36	14	49	3.86	60
TPJ		45	−40	19	4.07	43
pSTS		48	−52	4	4.85	71
Thalamus		−9	−22	13	3.99	51
Thalamus		6	−16	16	5.39	51
dACC		15	35	16	4.40	49
Chinese, Go Trials						
Ventral striatum		−23	18	1	4.55	5483[a]*
Ventral striatum		21	17	−5	4.44	[a]
STS		57	−19	−2	5.94	[a]
MFG	8	−42	29	22	4.78	[a]
IFG	45	−45	26	2	4.18	[a]
IFG	45	39	26	10	5.00	[a]
DMPFC	9	3	47	22	3.20	[a]
MFG	10	−30	61	10	5.14	156*
Middle occipital gyrus		−24	−88	10	5.41	226*
Middle temporal gyrus		12	56	4	6.27	209*
Temporal gyrus		−63	−19	7	4.34	99*
STS		−51	−46	10	6.12	119*
Precuneus		−21	−58	46	4.68	59
American, Go Trials						
Occipital lobe		33	−85	−5	6.00	185*
Occipital lobe		−27	−94	−8	4.54	70
IFG	45	−60	14	19	7.36	48

Note. x, y, and z refer to MNI coordinates; *t* refers to the t-score at those coordinates (local maxima); BA refers to putative Brodman's area. VLPFC refers to ventrolateral prefrontal cortex; DLPFC refers to dorsolateral prefrontal cortex; IFG refers to inferior frontal gyrus; MFG refers to middle frontal gyrus; STS refers to superior temporal sulcus; pSTS refers to posterior superior temporal sulcus; TPJ refers to temporal parietal junction; DMPFC refers to dorsomedial prefrontal cortex; dACC refers to dorsal anterior cingulate cortex. Clusters which survive FDR correction are noted with an *($p < .005$, 87 contiguous voxels). Resgions which share the same superscript are part of the same contiguous cluster.

fMRI results

Cultural differences in neural mechanisms during cognitive persistence

To examine whether participants show linear increases or decreases in neural activation across the task, we conducted parametric modulation analyses, in which we examined cultural differences in neural reactivity as a function of task block (1st, 2nd, 3rd) for go trials and nogo trials. We found a significant group difference (Chinese > American), such that for go trials, Chinese participants evidenced increased activation across the task blocks compared to American participants in the right IFG and ventral striatum (Table 1).

To further explore this effect, we ran whole-brain analyses within each cultural group separately. Whereas Chinese participants demonstrated increasing activation over the task blocks in the right IFG and VS, American participants did not show increasing activation in any of these regions (see Fig. 4a and Table 1). For descriptive purposes, we extracted parameter estimates of signal intensity from the striatum and IFG from each block of the task for Chinese and American participants separately. As shown in Fig. 4b, Chinese participants evidenced increasing IFG and VS activation over the course of the task, whereas American participants' neural reactivity in these regions remained stable. There were no significant differences between groups in neural activation during no-go trials.

Cultural differences in neural coupling underlying cognitive persistence

Next, we ran PPI analyses to examine whether the striatum showed functional coupling with frontal regions as a function of task block (1st, 2nd, 3rd) for go trials and nogo trials. Chinese participants evidenced increasing functional coupling across task blocks compared to American participants between the ventral striatum and IFG during go trials (xyz=40 ,28, −5, t(28)=4.73, $p < .005$, k=58). No other brain region was functionally coupled with the VS across the task. To further explore this effect, we ran PPI analyses within each cultural group seperately. Whereas Chinese participants demonstrated increasing coupling between the striatum and IFG over the task blocks (xyz=40, 28, −5, t(28)=4.95, $p < .005$, k=83), American participants did not show significant coupling in any regions (see Fig. 5a). For descriptive purposes, we extracted parameter estimates of signal intensity from the IFG from each block of the task for Chinese and American participants separately. As shown in Fig. 5b, Chinese participants evidenced increasing striatum-IFG connectivity over the course of the task, whereas American participants' neural connectivity in these regions remained around 0 across the task. There were no significant differences between groups in neural connectivity during no-go trials.

Links between cognitive persistence and neural activation

Our last set of analyses examined whether neural coupling between VS-IFG was associated with cognitive performance across the task. To examine change in false alarm rate across the task, we computed a difference score between the first and last block, such that lower scores represent declines in false alarms over the task (i.e., improvements in performance). We extracted parameter estimates of signal intensity from the IFG cluster which showed significant coupling with the VS. Results indicate that participants who show greater increases in VS-IFG functional coupling have greater improvements in cognitive performance over the task (r=−.53, $p < .005$; Fig. 6). We ran correlations separately for Chinese and American participants. Although not significant in either group alone due to low power, each group showed a negative association between VS-IFG functional coupling and cognitive performance, particularly in the Chinese sample who showed almost trend level significance and a larger effect size (Chinese: r=−.43, p=.11; American: r=−.16, p=.59).

Discussion

The current study takes a cross-cultural neuroscience perspective to unpack potential neurobiological processes underlying cultural differences in cognitive persistence. Across two studies, we show that American students show greater declines in cognitive performance across time, whereas Chinese students show persistence, even evidencing improved performance in Study 2. These behavioral effects were paralleled by increasing activation and functional coupling between the inferior frontal gyrus (IFG) and ventral striatum (VS) across the task among Chinese participants, neural activation that remained low in American participants. These findings suggest a potential neural mechanism by which the VS and IFG work in concert to promote cognitive persistence.

Chinese students' intrinsic motivation for self-improvement may rely on increasing recruitment of the IFG, a brain region involved in regulation and inhibitory control (Aron et al., 2004). Because Chinese youth are continually reinforced both at home and in school to engage in perseverance and self-improvement (Binco, 1992), they have been

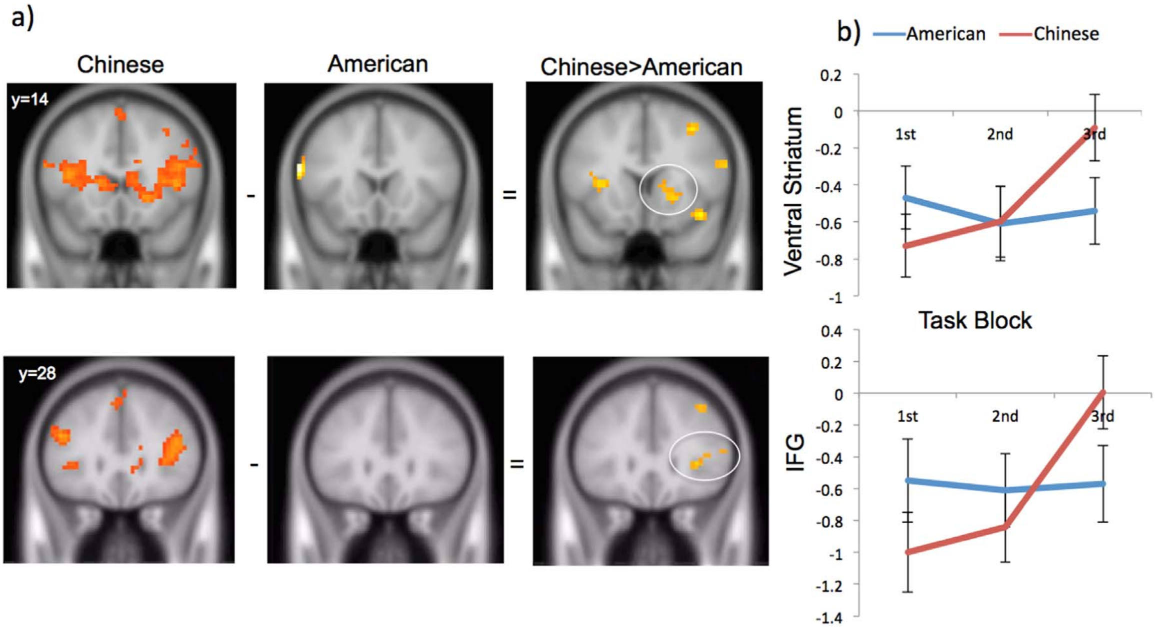

Fig. 4. (a) Neural regions which showed linear increases in functional reactivity across the task blocks during go trials for Chinese, American, and Chinese > American. (b) For descriptive purposes, we extracted parameter estimates of signal intensity and plotted neural reactivity during each block of the task for Chinese and American participants separately.

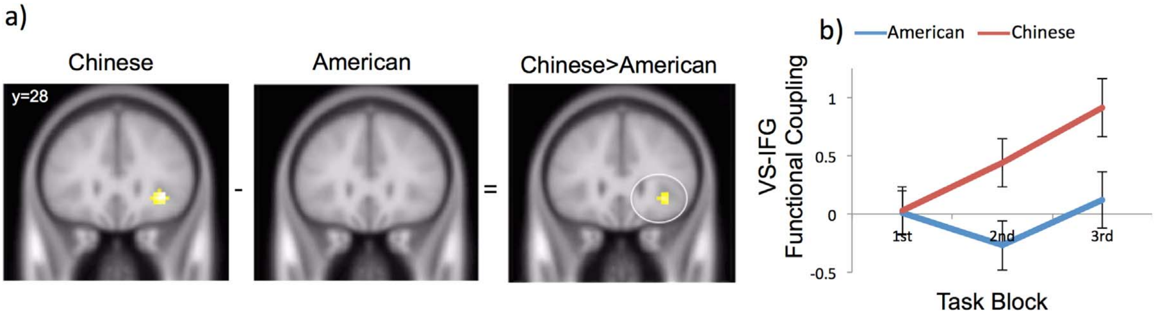

Fig. 5. PPI Analyses. (a) The IFG showed linear increases in functional connectivity with the ventral striatum across the task blocks during go trials for Chinese but not American participants. (b) For descriptive purposes, we extracted parameter estimates of signal intensity and plotted neural connectivity between the ventral striatum and IFG during each block of the task for Chinese and American participants separately.

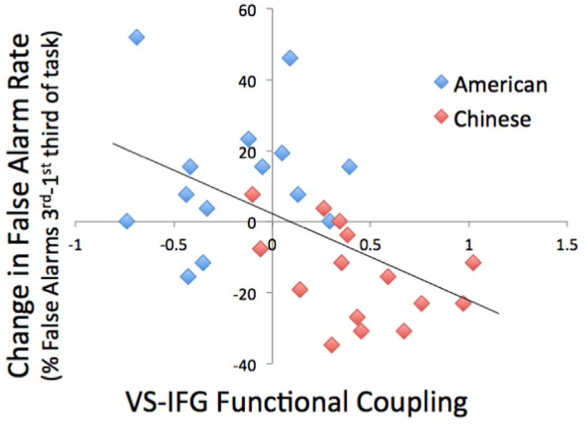

Fig. 6. Increased functional coupling between the ventral striatum and IFG over the course of the cognitive control task correlated with declines in false alarm rate.

provided with the learning context to practice cognitive control. This practice may shape the brain, supporting more effective cognitive engagement throughout development. Indeed, a recent longitudinal study showed that children in preschool who demonstrated poor delay-of-gratification (i.e., inability to resist a desireable stimulus) demonstrated greater false alarms (i.e., poorer behavioral inhibition) and lower IFG activation during a cognitive control task 40 years later (Casey et al., 2011). Thus, developmental experiences lay the foundation for neural processing of cognitive control.

In addition to cognitive control related brain function, Chinese participants showed increases in the ventral striatum, a brain region consistently linked with reward processing and motivation (Spear, 2011; Delgado, 2007). Effort is highly valued in East Asian culture (Heine et al., 2001) and students in China are socialized to see self-improvement and persistence in school as a moral endeavor (Li, 2004; Chao, 1994). Because engaging in behaviors that support the values of one's culture recruits the mesolimbic reward system, suggesting such behaviors are a rewarding experience (Telzer, Masten, Berkman, Lieberman, and Fuligni, 2010, 2011), striatal reactivity among Chinese students may be representing these cultural and moral endeavors. Thus, striatal reactivity may be a neurobiological signal representing intrinsic motivation that serves an adaptive function, increasing Chinese students' motivation to engage in cognitive persistence. On the other hand, American participants may not find cognitive persistence an intrinsically rewarding process and therefore give up, showing declines in cognitive performance over time.

In addition, we found that connectivity between the striatum and IFG facilitated improvements in cognitive persistence. Chinese students demonstrated increasing connectivity between the ventral striatum and IFG across the task blocks, connectivity that was absent in American students. Thus, ventral striatum activation may promote the motivation for Chinese students to engage in greater cognitive control and self-improvement. Indeed, we show that increasing functional connectivity between the ventral striatum and IFG was associated with improvements in cognitive performance over the course of the task, further supporting the notion that reward processes facilitate improved cognitive control. These findings are consistent with an emerging body of literature suggesting that rewards lead to improvements in cognitive control through bottom-up processes that increase activation in brain regions involved in regulation (Telzer et al., 2011; Geier et al., 2010; Smith, Berridge, and Aldridge, 2011). VS-IFG connectivity suggests that improvements in cognitive persistence among Chinese students may occur via a reward response that boosts their cognitive control system (i.e., VS activation elicits IFG activation), which, in part, underlies cognitive persistence and improved behavioral performance on the task. Together, our findings suggest that Chinese students' persistence may be subserved through reward processes that shape their motivation to engage in cognitive control and persevere through challenge.

Interestingly, all of our significant cultural group differences (increases in IFG activation, increases in ventral striatum activation, and increases in functional connectivity) were specific to go trials rather than no-go trials. Go-nogo tasks require both proactive (sustained attention) and reactive (response inhibition) aspects of executive control. Go trials require greater sustained attention (i.e., maintaining an efficient level of responding on a demanding task over a period of time (Ward, 2004), whereas nogo trials require response inhibition (i.e., the ability to override prepotent actions). Because our results show significant activations specific to go trials suggests that our cultural group differences are due, in part, to increases in sustained task attention among Chinese students, but attentional drift among American students.

Although our samples were matched on age and education level, it is possible that our Chinese participants differed in other key domains, such as general intelligence or cognitive flexibility. That Chinese participants had the motivation to attend secondary education abroad, and our American participants were relatively local could suggest the samples are different. Therefore, future studies should examine Chinese participants who are attaining education at similar institutions in China in order to determine whether our effects are generalizable to Chinese individuals more broadly. In addition, it is possible that our findings are specific to the task used in this study and do not generalize to other domains. Perhaps Chinese participants enjoyed the particular Go-Nogo task more than American participants. Thus, future studies should replicate these findings using diverse constructs and measures, perhaps using tasks that are more motivating or rewarding to American participants. Finally, our study focused on Chinese participants, yet other cultural groups beyond East Asians show strong self-improvement motivation (e.g., Chileans; Heine and Raineri, 2009). Therefore, the current findings may generalize to other populations who have strong self-improvement motivation, but this needs testing in future studies.

Our findings fit nicely into the *Biocultural Co-constructive Framework of Development,* in which cultural influences are continuously integrated into individuals' ontogeny and interwoven with neurobiological influences to shape behavioral, cognitive, and brain development across the life span (Li, 2003). Importantly, such processes are not fixed, and individuals do not merely serve as passive recipients of cultural processes. Instead, individuals can be active agents by making adaptive deicisions which can regulate the way biocultural influences play out (Li, 2003). Indeed, there are individual differences within cultures, as we found in the current study, and so self-improvement motivation can be actively supported by individuals, groups, or even societies to ultimately change cultural differences in motivation and persistence. These findings have important implications for improving the learning contexts of American students. East Asian students consistently outperform their American counterparts in academics (Baldi et al., 2007; PISA, 2012; TIMSS, 2011). Our study suggests that values and socialization processes embedded within culture shape cognitive persistence and the neural processes shaping motivation. Results of this study provide important insight for educational reform in the United States to prevent American students from disengaging. While extrinsic rewards and reinforcements are often used to increase motivation, extrinsic motivation can undermine intrinsic forms of motivation. We show that effective cognitive persistence can be improved with effort, and that such effort can be an intrinsically rewarding process. Teachers, parents, and policy makers should therefore focus on supporting self-improvement and persistence, skills that will likely result in better engagement in school. By placing value on effort, self-improvement may become a more rewarding process for American students, and they may be less likely to give up in the face of challenge.

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References

Aron, A.R., Robbins, T.W., Poldrack, R.A., 2004. Inhibition and the right inferior frontal cortex. Trends Cogn. Sci. 8 (4), 170–177.
Baldi, S., Jin, Y., Skemer, M., Green, P.J., Herget, D., 2007. Highlights from PISA 2006: performance of U.S. 15-year-old students in science and mathematics literacy in an international context. Natl. Cent. Educ. Stat., Inst. Educ. Sci., U. S. Dep. Educ..
Binco, P.M., 1992. A cross-cultural study of task persistence of young children in Japan and the United States. J. Cross-Cult. Psychol. 23 (3), 407–415.
Brass, M., Derrfuss, J., Forstmann, B., Cramon, D., 2005. The role of the inferior frontal junction area in cognitive control. Trends Cogn. Sci. 9 (7), 314–316.
Bunge, S.A., 2004. How we use rules to select actions: a review of evidence from cognitive neuroscience. Cogn., Affect., Behav. Neurosci. 4 (4), 564–579.
Casey, B.J., Somerville, L.H., Gotlib, I.H., Ayduk, O., Franklin, N.T., Askren, M.K., Glover, G., 2011. Behavioral and neural correlates of delay of gratification 40 years later. Proc. Natl. Acad. Sci. 108 (36), 14998–15003.
Chao, R.K., 1994. Beyond parental control and authoritarian parenting style: understanding Chinese parenting through the cultural notion of training. Child Dev. 65 (4), 1111–1119.
Chao, R., Tseng, V., 2002. Parenting of Asians. In M. H. Bornstein (Ed.), Handbook of parenting: Vol. 4: Social conditions and applied parenting (2nd ed., pp. 59-93). Mahwah, NJ: Lawrence Erlbaum.
Deci, E.L., Cascio, W.F., April 1972. Changes in Intrinsic Motivation as a Function of Negative Feedback and Threats. Paper presented at Eastern Psychological Association Meeting, Boston, Mass.
Deci, E.L., Koestner, R., Ryan, R.M., 1999. A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation.
Deci, E.L., Vallerand, R.J., Pelletier, L.G., Ryan, R.M., 1991. Motivation and education: The self-determination perspective. Educ. Psychol. 26 (3-4), 325–346.
Delgado, M.R., 2007. Reward-related responses in the human striatum. Ann. New Y. Acad. Sci. 1104 (1), 70–88.
Delgado, M.R., Locke, H.M., Stenger, V.A., Fiez, J.A., 2003. Dorsal striatum responses to reward and punishment: effects of valence and magnitude manipulations. Cogn. Affect. Behav. Neurosci. 3 (1), 27–38.
Delgado, M.R., Nystrom, L.E., Fissell, C., Noll, D.C., Fiez, J.A., 2002. Tracking the hemodynamic responses to reward and punishment in the striatum. J. neurophysiol. 84 (6), 3072–3077.
Elliott, R., Newman, J.L., Longe, O.A., William Deakin, J.F., 2004. Instrumental respondingfor rewards is associated with enhanced neuronal response in subcortical rewardsystems. NeuroImage 21, 984–990.
Egner, T., 2011. Right ventrolateral prefrontal cortex mediates individual differences in conflict-driven cognitive control. J. Cogn. Neurosci. 23 (12), 3903–3913.
Friston, K.J., Buechel, C., Fink, G.R., Morris, J., Rolls, E., Dolan, R.J., 1997. Psychophysiological and modulatory interactions in neuroimaging. Neuroimage 6 (3), 218–229.
Gartstein, M.A., Gonzalez, C., Carranza, J.A., Ahadi, S.A., Ye, R., Rothbart, M.K., Yang, S.W., 2006. Studying cross-cultural differences in the development of infant temperament: People's Republic of China, the United States of America, and Spain. Child Psychiatry Human. Dev. 37 (2), 145–161.
Geier, C.F., Terwilliger, R., Teslovich, T., Velanova, K., Luna, B., 2009. Immaturities in reward processing and its influence on inhibitory control in adolescence. Cerebral

Cortex, bhp225.

Geier, C.F., Terwilliger, R., Teslovich, T., Velanova, K., Luna, B., 2010. Immaturities in reward processing and its influence on inhibitory control in adolescence. Cereb. Cortex 20 (7), 1613–1629.

Gneezy, U., Meier, S., Rey-Biel, P., 2011. When and why incentives (don't) work to modifybehavior. Journal Economic Perspectives 25, 191–210.

Heine, S.J., Hamamura, T., 2007. In search of East Asian self-enhancement. Personal. Social. Psychol. Rev. 11, 1–24.

Heine, S.J., Lehman, D.R., Ide, E., Leung, C., Kitayama, S., Takata, T., Matsumoto, H., 2001. Divergent consequences of success and failure in Japan and North America: an investigation of self-improving motivations and malleable selves. J. Personal. Social. Psychol. 81 (4), 599–615.

Heine, S.J., Raineri, A., 2009. Self-improving motivations and collectivism the case of Chileans. J. Cross-Cult. Psychol. 40 (1), 158–163.

Hess, R.D., Chang, C.M., McDevitt, T.M., 1987. Cultural variations in family beliefs about children's performance in mathematics: comparisons among People's Republic of China, Chinese-American, and Caucasian-American families. J. Educ. Psychol. 79 (2), 179–188.

Ikemoto, S., Panksepp, J., 1999. The role of nucleus accumbens dopamine in motivated behavior: a unifying interpretation with special reference to reward-seeking. Brain Res. Rev. 31 (1), 6–41.

Kirsch, P., Schienle, A., Stark, R., Sammer, G., Blecker, C., Walter, B., Ott, U., Burkart, J., Vaitl, D., 2003. Anticipation of reward in a nonaversive differential conditioningparadigm and the brain reward system: an event-related fMRI study. NeuroImage 20, 1086–1095.

Knutson, B., Cooper, J.C., 2005. Functional magnetic resonance imaging of reward prediction. Curr. Opin. Neurol. 18 (4), 411–417.

Knutson, B., Westdorp, A., Kaiser, E., Hommer, D., 2000. fMRI visualization of brainactivity during a monetary incentive delay task. NeuroImage 12, 20–27.

Kouneiher, F., Charron, S., Koechlin, E., 2009. Motivation and cognitive control in the human prefrontal cortex. Nat. Neurosci. 12 (7), 939–945.

Lan, X., Legare, C.H., Ponitz, C.C., Li, S., Morrison, F.J., 2011. Investigating the links between the subcomponents of executive function and academic achievement: a cross-cultural analysis of Chinese and American preschoolers. J. Exp. Child Psychol. 108 (3), 677–692.

Levy, B.J., Wagner, A.D., 2011. Cognitive control and right ventrolateral prefrontal cortex: reflexive reorienting, motor inhibition, and action updating. Ann. New Y. Acad. Sci. 1224 (1), 40–62.

Li, S.C., 2003. Biocultural orchestration of developmental plasticity across levels: the interplay of biology and culture in shaping the mind and behavior across the life span. Psychol. Bull. 129 (2), 171–194.

Li, J., 2004. Learning as a task or a virtue: U.S. and Chinese preschoolers explain learning. Dev. Psychol. 40 (4), 595–605.

Lieberman, M.D., Cunningham, W.A., 2009. Type I and Type II error concerns in fMRI research: re-balancing the scale. Social. Cogn. Affect. Neurosci. 4 (4), 423–428.

Matsumoto, K., Suzuki, W., Tanaka, K., 2003. Neuronal correlates of goal-based motor selection in the prefrontal cortex. Science 301 (5630), 229–232.

Maldjian, J.A., Laurienti, P.J., Kraft, R.A., Burdette, J.H., 2003. An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. Neuroimage 19 (3), 1233–1239.

McLaren, D.G., Ries, M.L., Xu, G., Johnson, S.C., 2012. A generalized form of context-dependent psychophysiological interactions (gPPI): a comparison to standard approaches. Neuroimage 61 (4), 1277–1286.

Murayama, K., Matsumoto, M., Izuma, K., Matsumoto, K., 2010. Neural basis of the undermining effect of monetary reward on intrinsic motivation. Proc. Natl. Acad. Sci. USA 107 (49), 20911–20916.

Neubert, F.X., Mars, R.B., Thomas, A.G., Sallet, J., Rushworth, M.F., 2014. Comparison of human ventral frontal cortex areas for cognitive control and language with areas in monkey frontal cortex. Neuron 81 (3), 700–713.

Padmanabhan, A., Geier, C.F., Ordaz, S.J., Teslovich, T., Luna, B., 2011. Developmental changes in brain function underlying the influence of reward processing on inhibitory control. Dev. Cognit. Neurosci. 1 (4), 517–529.

Pessiglione, M., Seymour, B., Flandin, G., Dolan, R.J., Frith, C.D., 2006. Dopamine-dependent prediction errors underpin reward-seeking behaviour in humans. Nature 442 (7106), 1042–1045.

PISA, 2012. PISA 2012 Results, Retrieved August 24, 2014, from ⟨http://www.oecd.org/pisa/keyfindings/PISA-2012-results-snapshot-Volume-I-ENG.pdf⟩.

Preacher, K.J., Hayes, A.F., 2008. Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. Behav. Res. Methods 40, 879–891.

Qu, Y., Pomerantz, E.M., Deng, C., 2016. Mothers' goals for Adolescents in the United States and China: content and transmission. J. Res. Adolesc. 26 (1), 126–141.

Reeve, J., Deci, E.L., 1996. Elements of the competitive situation that affect intrinsic motivation. Personal. Soc. Psychol. Bull. 22 (1), 24–33.

Ryan, R.M., Deci, E.L., 2000. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. Am. Psychol. 55, 68–78.

Sabbagh, M.A., Xu, F., Carlson, S.M., Moses, L.J., Lee, K., 2006. The development of executive functioning and theory of mind: a comparison of Chinese and U.S. preschoolers. Psychol. Sci. 17 (1), 74–81.

Satterthwaite, T.D., Ruparel, K., Loughead, J., Elliott, M.A., Gerraty, R.T., Calkins, M.E., Wolf, D.H., 2012. Being right is its own reward: load and performance related ventral striatum activation to correct responses during a working memory task in youth. Neuroimage 61 (3), 723–729.

Smith, K.S., Berridge, K.C., Aldridge, J.W., 2011. Disentangling pleasure from incentive salience and learning signals in brain reward circuitry. Proc. Natl. Acad. Sci. 108 (27), E255–E264.

Spear, L.P., 2011. Rewards, aversions and affect in adolescence: emerging convergences across laboratory animal and human data. Dev. Cogn. Neurosci. 1 (4), 390–403.

Stevenson, H.W., Lee, S.Y., Chen, C., Stigler, J.W., Hsu, C.C., Kitamura, S., Hatano, G., 1990. Contexts of achievement: a study of American, Chinese, and Japanese children. Monogr. Soc. Res. Child Dev., 119.

Sun, Y., 2011. Cognitive advantages of East Asian American children: when do such advantages emerge and what explains them? Sociol. Perspect. 54 (3), 377–402.

Telzer, E.H., Masten, C.L., Berkman, E.T., Lieberman, M.D., Fuligni, A.J., 2010. Gaining while giving: an fMRI study of the rewards of family assistance among White and Latino youth. Social. Neurosci. 5 (5), 508–518.

Telzer, E.H., Masten, C.L., Berkman, E.T., Lieberman, M.D., Fuligni, A.J., 2011. Neural regions associated with self control and mentalizing are recruited during prosocial behaviors towards the family. Neuroimage 58 (1), 242–249.

TIMSS, 2011. Mathematics achievement of fourth- and eighth-graders in 2011, (Retrieved August 24, 2014)⟨https://nces.ed.gov/TIMSS/results11_math11.asp⟩.

Tobin, J.J., Wu, D.Y.H., Davidson, D.H., 1989. Preschool in three Cultures: Japan, China, and the United States. Yale University Press, New Haven, CT.

Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., Joliot, M., 2002. Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. Neuroimage 15 (1), 273–289.

Ward, B.D., 2000. Simultaneous inference for fMRI data. Retrieved August 10, 2014, from ⟨http://afni.nimh.nih.gov/afni/doc/manual/AlphaSim⟩.

Ward, A., 2004. Attention: A Neuropsychological Perspective. Psychology Press, New York, NY.