



# The matter of motivation: Striatal resting-state connectivity is dissociable between grit and growth mindset

Chelsea A. Myers,<sup>1,\*</sup> Cheng Wang,<sup>1,\*</sup> Jessica M. Black,<sup>2</sup> Nicolle Bugescu,<sup>3</sup> and Fumiko Hoeft<sup>1,4,5</sup>

<sup>1</sup>Department of Psychiatry and Weill Institute for Neurosciences, University of California San Francisco, 401 Parnassus Ave, San Francisco, CA 94143, USA, <sup>2</sup>School of Social Work, Boston College, 140 Commonwealth Ave, Chestnut Hill, MA 02467, USA, <sup>3</sup>Nationwide Children's Hospital, 700 Children's Drive, Columbus, OH 43205, USA, <sup>4</sup>Haskins Laboratories, Yale University, 300 George St, Suite 900, New Haven, CT 06511, USA and <sup>5</sup>Department of Neuropsychiatry, Keio University School of Medicine, 35 Shinanomachi, Shinjuku-Ku, Tokyo 160-8582, Japan

Correspondence should be addressed to Fumiko Hoeft, Department of Psychiatry and Weill Institute for Neurosciences, University of California San Francisco, 401 Parnassus Ave., San Francisco, CA 94143, USA. E-mail: Fumiko.Hoeft@ucsf.edu

\*C.A. Myers and C. Wang contributed equally to this work.

## Abstract

The current study utilized resting-state functional magnetic resonance imaging (fMRI) to examine how two important non-cognitive skills, grit and growth mindset, are associated with cortico-striatal networks important for learning. Whole-brain seed-to-voxel connectivity was examined for dorsal and ventral striatal seeds. While both grit and growth mindset were associated with functional connectivity between ventral striatal and bilateral prefrontal networks thought to be important for cognitive-behavioral control. There were also clear dissociations between the neural correlates of the two constructs. Grit, the long-term perseverance towards a goal or set of goals, was associated with ventral striatal networks including connectivity to regions such as the medial prefrontal and rostral anterior cingulate cortices implicated in perseverance, delay and receipt of reward. Growth mindset, the belief that effort can improve talents, notably intelligence, was associated with both ventral and dorsal striatal connectivity with regions thought to be important for error-monitoring, such as dorsal anterior cingulate cortex. Our findings may help construct neurocognitive models of these non-cognitive skills and have critical implications for character education. Such education is a key component of social and emotional learning, ensuring that children can rise to challenges in the classroom and in life.

**Key words:** resting-state fMRI; grit; growth mindset; character education; functional connectivity

## Introduction

High-stakes testing epitomizes the long-standing attribution of cognitive skills to success. This focus has monopolized students' classroom time and left little resources for development of non-cognitive skills (e.g. perseverance, mindset) critical to social and emotional learning (SEL). However, a growing body of evidence associates non-cognitive skills with academic outcomes (Blackwell *et al.*, 2007; Duckworth *et al.*, 2007), and thus

has begun to gain traction in academic policy. Emerging alongside the SEL movement's growing popularity come a number of gaps in the evidence needed to feasibly embark on widespread integration in educational practice. First, studies have shown that a number of non-cognitive skills can be developed (Cunha and Heckman, 2008), but their underlying mechanisms have yet to be explored to elucidate how they interact with cognitive traits. Second, SEL, non-cognitive skills and character education

Received: 29 February 2016; Revised: 29 February 2016; Accepted: 5 May 2016

© The Author (2016). Published by Oxford University Press. For Permissions, please email: journals.permissions@oup.com

have all emerged as catch-all terms that combine many potentially distinct constructs (Heckman and Rubinstein, 2001).

It is important moving forward to understand the uniqueness and similarities of these skills in order to improve measurement and understand their implementation. This may help to unpack non-cognitive skills into manageable parts subject to intervention. Neuroscience research has been an important contributor to supporting and refining models of cognitive skills and abilities central to schooling, such as reading and math, and has played a pivotal role in developing well-informed interventions. Such an integrative research approach incorporating behavioral and neurological query is well suited for developing our understanding of non-cognitive skills.

Here, we examine the neural correlates of two important non-cognitive skills: grit and mindset. Grit is the *long-term perseverance for a goal or set of goals*. Duckworth et al. (2007) found that grit scores accounted for an average of four percent of the variance in success outcomes even beyond scores of intelligence and conscientiousness (p. 1087). These authors arrived at this figure by averaging the percent variance in success scores explained by grit across six of their studies with a range of percent variance (1.4–6.3%) and varying aims (such as predicting: grade point average (GPA), educational attainment and spelling bee rankings). More recent studies also demonstrate the unique contribution grit has to success outcome including: completing an Army Special Operations Forces selection course, job retention, graduating from Chicago Public Schools, and remaining married for men (Eskreis-Winkler et al., 2014). Taken together, these findings, while small, consistently underscore the importance of long-term perseverance for difficult goals over and above the contribution of talent to success outcomes (Duckworth et al., 2007; Eskreis-Winkler et al., 2014).

Mindset refers to the views one holds about the malleability of ability and was assessed using a theory of intelligence scale. A growth mindset (an incremental theory of intelligence) is the belief that intelligence is malleable and that one may ‘grow’ their intelligence and *achieve their goals through hard work and dedication*; a fixed mindset (entity theory of intelligence) is the belief that talents and intelligence cannot be changed (Dweck, 2006). Growth mindset is not only positively correlated with math achievement for seventh graders (Blackwell et al., 2007), but more powerfully, experimental studies demonstrate that shaping or operationalizing growth mindset impacts the motivation and performance for aspiring clinicians in organic chemistry (Grant and Dweck, 2003), and for minority students in the face of stereotypes about their race and perceived intelligence (Aronson et al., 2002).

The constructs of grit and mindset have been brought into focus among educators seeking to shape non-cognitive skills to positively impact measures of success from academic achievement to life outcome. Recent evidence suggests that the two constructs are moderately correlated ( $r = 0.18$ ,  $P < 0.001$ ) (West et al., 2014). In unpublished cross-sectional studies of school-aged children, Duckworth and colleagues found positive associations between grit and growth mindset, leading the authors to speculate that growth mindset may contribute to propensity for goal commitment and sustained effort (Duckworth and Eskreis-Winkler, 2013; Perkins-Gough, 2013). Therefore, shaping a growth mindset may be an intervention pathway to help an individual develop grit.

Though related, presumably by overlapping motivation strategies, how do grit and growth mindset dissociate? Whereas growth mindset is the malleable view that our intelligence can be improved through effort and has been studied extensively in

theoretical, correlational and experimental work, grit has entered the motivation literature much more recently (Duckworth et al., 2007; Duckworth and Quinn, 2009; Eskreis-Winkler et al., 2014). As Duckworth et al. (2007) has found, someone who is gritty ‘approaches achievement as a marathon’ (p. 1088). These individuals are not deterred by boredom or setbacks, but rather they remain steadfast toward their goals (Duckworth et al., 2007). Motivation for the gritty individual is long-term, whether that is to be a top-notch researcher or to win an Olympic gold medal. A person with a growth mindset also believes in the efficacy of hard work and dedication to improve their abilities, but may not necessarily hold a definitive reward in mind as the outcome. Instead, these individuals self-regulate their learning on a regular basis, characterized by goal setting, goal operating and goal monitoring (Burnette et al., 2013), employing strategies such as learning from new knowledge and adjusting when errors are made.

In this study, we sought to further understand the similarities and differences between grit and growth mindset by examining associated brain networks in a sample of children using resting state functional connectivity (RSFC). RSFC, measured by functional magnetic resonance imaging (fMRI), is thought to reflect the brain’s functional organization (van den Heuvel and Hulshoff Pol, 2010). Due to our interest in bridging motivation and learning and the known importance of the striatum to reward-related learning (Shohamy, 2011; Liljeholm and O’Doherty, 2012; Pauli et al., 2016), we focused on dorsal and ventral striatal (dStr, vStr) connectivity and adopted whole-brain seed-to-voxel analyses. Since growth mindset is a belief system that favors hard work and performance monitoring and grit is a combination of long-term effort, we hypothesized that the striatal connectivity for growth mindset and grit would overlap in regions of the prefrontal cortex implicated in cognitive-behavioral control and dissociate in regions implicated in error-monitoring (e.g. dorsal anterior cingulate cortex) and in affective response (e.g. rostral anterior cingulate cortex).

## Materials and methods

### Participants

Twenty healthy children (9 females, average age 11.2) were included from a larger study with a primary focus on examining the neural pathways important for academic achievement in native-English speakers in the US (refer to Supplementary material, Table S1 for demographic information). A comprehensive socio-emotional survey was administered approximately 2 years, on average, following collection of structural and resting-state functional MRI scans (refer to Supplementary material text and Table S1 for further details).

### Behavioral measures

The grit scale was developed by Duckworth and Quinn (2009) to capture an individual’s passion and persistence towards long-term goals. Participants responded to a collection of eight items (e.g. ‘New ideas and projects sometimes distract me from old ones’), each of which was rated on a 5-point Likert scale. Participants’ grit scores were then calculated from responses across eight items. Indexed by Cronbach’s alpha, the scale had an internal consistency of  $\alpha = 0.80$  in our sample.

To assess mindset, the theory of intelligence scale was administered (Dweck, 1999). The measure consists of six items,

three entity theory statements (e.g. 'You have a certain amount of intelligence, and you really can't do much to change it.') and three incremental theory statements (e.g. 'You can always greatly change how intelligent you are.'). Participants were asked to rate their agreement with each statement using a 6-point scale. The mean on the six-item scale indicated the participant's mindset, with greater scores (i.e. closer to 6) representing a growth mindset. The internal consistency of this scale was  $\alpha = 0.84$  in our sample.

### MRI data collection

Imaging data were collected at the Richard M. Lucas Center for Imaging at Stanford University in the summer and fall of 2011 and 2012. Prior to the scanning session, families received a packet of materials, including a CD of scanner noises and a DVD of a child going into a scanner, designed to prepare him/her for the scanner sounds and environment. To further minimize movement, children participated in simulated MRI sessions at the Center for Interdisciplinary Brain Sciences Research (<http://cibr.stanford.edu/participating/Simulator.html>).

MRI data were acquired using a GE Healthcare 3.0 T scanner 20.x software revision and an 8-channel phased array head coil (GE Healthcare, Waukesha, WI). Images acquired included an axial-oblique 3D T1-weighted sequence with fast spoiled gradient recalled echo pulse sequence (inversion recovery preparation pulse (TI) = 400 ms; repetition time (TR) = 5.5 ms; echo-time (TE) = 1.7 ms; flip angle = 30°; Receiver bandwidth + 32 kHz; slice thickness = 1.2 mm; 156 slices; NEX = 1; field-of-view (FOV) = 22 cm; Phase FOV = 0.75; acquisition matrix = 256 × 256). All scans were inspected by three experienced imaging researchers, without the knowledge of the purpose of the study, for the presence of excessive motion and excluded when agreed upon by the researchers.

Functional MRI data were acquired using an axial 2D GRE Spiral In/Out (Glover and Law, 2001) pulse sequence (repetition time [TR] = 2000 ms; echo time [TE] = 30 ms; flip angle = 80°; Receiver band-width = 125 kHz; slice thickness = 4.0 mm; number of slices = 31, descending; 3.44 × 3.44 mm in-plane resolution; number of temporal frames = 180; field of view [FOV] = 22 cm). The total duration of the resting state scan was 6 min.

### Image preprocessing

The Statistical Parametric Mapping 8 statistical package (SPM8; <http://www.fil.ion.ucl.ac.uk/spm>) including the voxel based morphometry (VBM8) and Diffeomorphic Anatomical Registration Through Exponentiated Lie Algebra (DARTEL) toolboxes (Ashburner, 2007) was used in the preprocessing of the structural images. Images were bias-field corrected and segmented to gray matter, white matter and cerebrospinal fluid (CSF).

Processing of resting state fMRI data was performed with SPM8 in the MATLAB computing environment (The MathWorks, Natick, MA). Data were corrected for acquisition timing and realigned to the third volume of the series. To reduce the effect of head movement on functional connectivity, volumes with a mean intensity >1.5% of the mean global signal or 0.5 mm/TR framewise displacement were detected and repaired via interpolation using the ArtRepair toolbox (Mazaika et al., 2009). After artifact repair, data were spatially normalized to MNI space using normalization parameters obtained from the children's segmented gray matter images transformed to the MNI standard template. Resultant images were re-sampled to 2 × 2 ×

2 mm voxels in MNI stereotaxic space. Spatial smoothing was done with a 7-mm isotropic Gaussian kernel. Functional data were analyzed for the presence of motion and excluded if relative motion exceeded 1.0 mm.

### Region-of-interest selection

The primary goal of this study was to investigate the behavioral and neurological similarities and differences underlying grit and growth mindset. These traits have been shown to predict success in a variety of domains [e.g. for grit: Duckworth et al. (2007); Duckworth and Quinn (2009); Eskreis-Winkler et al. (2014); e.g. for growth mindset: Aronson et al. (2002); Blackwell et al. (2007); Good et al., (2003)]. As mentioned, grit is perseverance for long-term goals. A growth mindset is marked by a malleable view of intelligence, that is, an individual with a growth mindset will believe that through hard work and dedication intelligence can be improved and goals can be met. By definition, these constructs appear to both highlight the importance of hard work in the pursuit of goals. Thus, we aimed to select our regions-of-interest (ROI) to best characterize the neural overlap and dissociations of these two non-cognitive traits.

Due to the well-known connections with motivation, reward and learning (Shohamy, 2011; Liljeholm and O'Doherty, 2012; Pauli et al., 2016), we selected ROIs of the ventral and dorsal striatum. In order to construct these ROIs, we combined the left and right nucleus accumbens, caudate and putamen from the Harvard-Oxford Subcortical Structural Atlas (Harvard Center for Morphometric Analysis), and divided the ventral and dorsal striatum at MNI coordinate  $z=0$  according to the procedure in Cooper et al. (2012). The resultant two clusters, bilateral ventral striatum ( $z < 0$ ) and bilateral dorsal striatum ( $z > 0$ ) were input as seed ROIs in the functional connectivity analysis run in Conn Toolbox for SPM (Whitfield-Gabrieli and Nieto-Castanon, 2012).

### Resting-state functional magnetic resonance imaging connectivity analysis

Resting-state connectivity analyses were performed using the Conn Toolbox (version 13o) for SPM (Whitfield-Gabrieli and Nieto-Castanon, 2012). Within the toolbox, the CompCor method was adopted (Behzadi et al., 2007). Subject-specific white matter and CSF time series were extracted and the first five principal components of each were regressed from the BOLD signal as were the three translation and three rotation movement parameters calculated during realignment in SPM. The residual BOLD signal was band-pass filtered (0.008-0.09 Hz), regressing out the first five principal components derived from subject-specific time series to focus on low-frequency oscillations typically seen in resting-state networks. Primary analysis focused on whole-brain functional connectivity seeded from the bilateral striatum ROIs (defined above). The mean-centered values of grit and growth mindset were input as covariates in models both independently and simultaneously to observe simple and partial correlation effects in the model from the seeded regions.

The statistical significance threshold for whole-brain analyses was determined by Monte Carlo simulation using 3dClustSim in AFNI (Cox, 1996). Analyses were further Bonferroni corrected for the number of ROIs used, such that clusters were significant at  $P = 0.025$ , which dictated that results were limited to voxel height of  $P < 0.02$  and cluster-size of at least 449 contiguous voxels by volume ( $P = 0.05$  Bonferroni



corrected for the number of ROIs and for the whole brain). All reported coordinates are in MNI space.

## Results

### Demographics and behavioral correlations

Descriptive statistics of demographic and behavioral variables are presented in Supplementary material, Table S1. In addition, similarities and differences between grit and intelligence beliefs were observed in a series of correlational analyses. (Supplementary material, Table S2). Grit and growth mindset showed small correlation in line with prior research, but likely due to small sample size, the effect was not significant ( $r = 0.34$ ,  $P = 0.14$ ).

### Striatal resting-state connectivity correlations with grit and mindset

Simple correlations between striatal functional connectivity and grit and growth mindset yielded a number of positive resting-state networks ( $P < 0.05$  Bonferroni corrected for the number of ROIs and for the whole brain; Figure 1 and Supplementary material, Tables S3 and S4 for details and negative correlations). Dorsal striatal connectivity with a number of regions was positively correlated with greater growth mindset; grit showed no significant positive correlations with dStr

connectivity. These included dorsal anterior cingulate cortex (dACC)/anterior midcingulate cortex (amCC), left dorsolateral prefrontal cortex (DLPFC) and cerebellum (Figure 1a and Supplementary material, Table S3). When regressing growth mindset on grit, the results remained significant and new clusters emerged including connectivity between dStr and a large cluster spanning right middle frontal gyrus, pre-central gyrus and superior frontal gyrus, as well as a cluster proximal to the left pre-central gyrus (Figure 2a and Supplementary material, Table S4).

In contrast, vStr networks were associated with both grit and mindset. First, both greater grit and growth mindset showed positive correlations between vStr connectivity and DLPFC that spatially overlapped (Figure 1b and Supplementary material, Table S3). Only vStr connectivity with right DLPFC remained significantly correlated with greater grit when controlling for growth mindset. Connectivity between vStr and left DLPFC remained correlated with mindset when grit was controlled for. Greater grit was characterized by statistically significant vStr connectivity with rostral ACC (rACC), medial PFC (mPFC), including the right frontal pole, and a cluster in the posterior CC (PCC; in both simple correlation and multiple regression with grit regressing out growth mindset) (Figures 1b and 2b and Supplementary material, Tables S3, S4). A greater growth mindset was positively correlated with connectivity between the vStr and a number of dispersed bilateral regions. These clusters included a region in the cerebellum, a cluster proximal to the

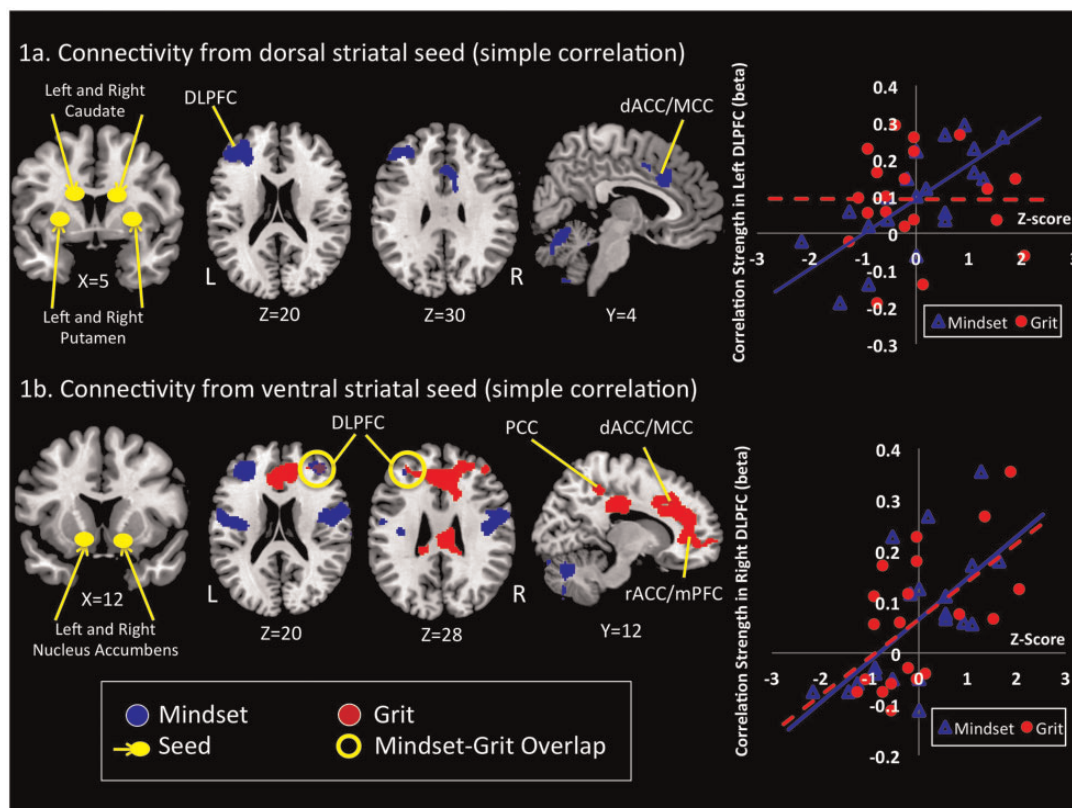


Fig. 1. Striatal networks of grit and mindset (Positive Simple Correlation). Clusters depicted were significant at  $P = 0.05$  Bonferroni corrected for the number of ROIs and the whole brain. (A) Resting state functional dorsal striatal connectivity correlation with mindset (blue). No positive dorsal striatum connectivity with grit. Panel on the right is a scatter plot of connectivity strength from dorsal striatal ROI to left dorsolateral prefrontal cortex (DLPFC) plotted against grit (red) and mindset (blue). The left DLPFC cluster is shown on the left panel at  $z = 20$ . Grit and mindset are in z scores. Linear best-fit lines are shown. (B) Resting state functional ventral striatal connectivity correlation with mindset (blue) and grit (red). Overlapping regions are depicted in purple. Panel on the right is a scatter plot of connectivity strength from ventral striatal ROI to right dorsolateral prefrontal cortex (DLPFC) plotted against grit (red) and mindset (blue). The right DLPFC cluster is shown on the left panel at  $z = 28$ . Grit and mindset are in z scores. Linear best-fit lines are shown.

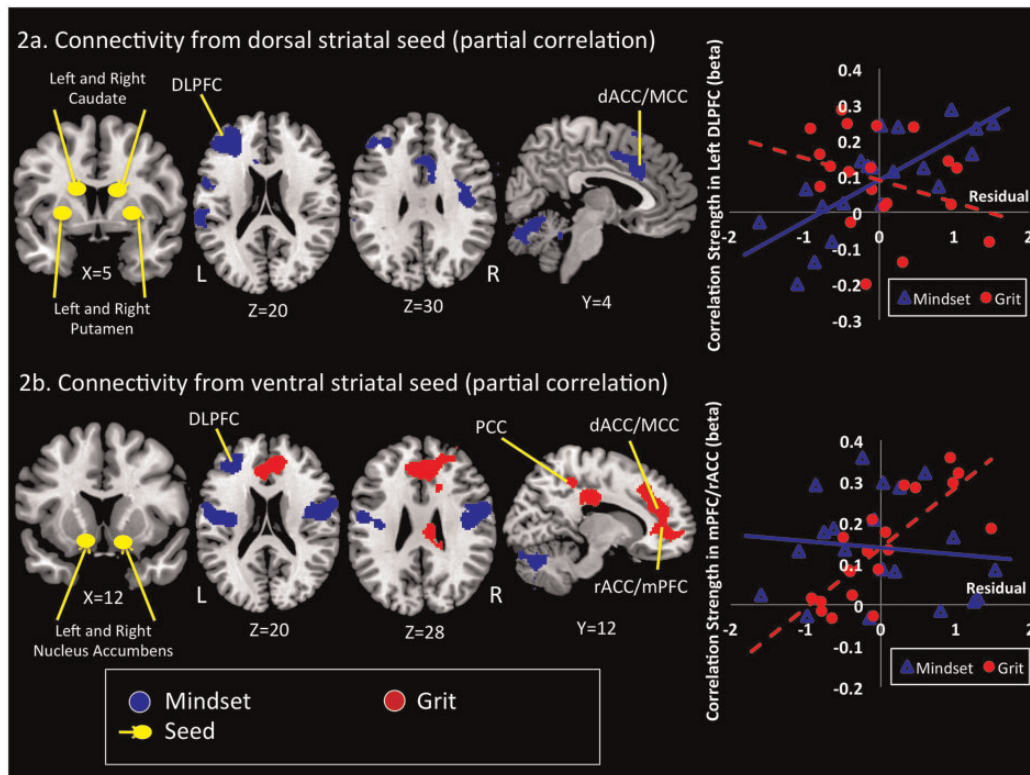


Fig. 2. Striatal networks of grit and mindset (positive partial correlation). Clusters depicted were significant at  $P = 0.05$  Bonferroni corrected for the number of ROIs and for the whole brain. (A) Resting state functional dorsal striatal connectivity correlation with mindset while regressing out grit (blue). No positive dorsal striatum connectivity with grit while regressing out mindset. Panel on the right is a scatter plot of connectivity strength from dorsal striatal ROI to left dorsolateral prefrontal cortex (DLPFC) plotted against grit (red) and mindset (blue). The left DLPFC cluster is shown on the left panel at  $z = 20$ . Grit and mindset are in  $z$  scores. (B) Resting state functional ventral striatal connectivity correlation with mindset (blue) and grit (red). Overlapping regions are depicted in purple. Panel on the right is a scatter plot of connectivity strength from ventral striatal ROI to medial prefrontal/rostral anterior cingulate (MPFC/rACC) plotted against grit (red) and mindset (blue). The MPFC/rACC is shown on the left panel at  $y = 12$ . Grit and mindset are residualized for the opposite and represented in  $z$  scores.

right pre-central and post-central gyri, and a left pre-central gyrus/opercular cortex cluster (in both simple correlation and multiple regression with growth mindset regressing out grit) (Figures 1b and 2b and Supplementary material, Tables S3, S4). The imaging correlations with each of the two grit factors, consistency of interest and perseverance of effort, are also described in Supplementary material (see Supplementary, Results 'Imaging Correlations with Two Grit Factors').

## Discussion

The striatum is thought to modulate information from regions involved in reward processing and executive functioning including those related to cognitive and behavioral control (Averbeck et al., 2014). Broadly speaking, the dStr is characterized as the 'actor', which holds information about favorable outcomes to ensure that favorable choices are made more frequently and suggested to be involved in cognitive and motor control (O'Doherty et al., 2004). The vStr on the other hand is involved in reward processing, motivation and decision-making. The vStr is hence most often differentiated for its contribution as a 'critic', which 'learns to predict future reward' (O'Doherty et al., 2004). These distinctions, however, are not black and white and work describing a dorsolateral-to-ventromedial gradient in the striatum has been explored. Of relevance, dStr and vStr mediate different dimensions of cognitive flexibility and inhibitory control (Voorn et al., 2004). In our

data, grit and growth mindset were both related to corticostriatal connectivity between vStr and DLPFC, which has been shown to be impaired in those with substance abuse and related to cognitive-behavioral control, more specifically, inhibition, or the ability to ignore irrelevant or harmful stimuli (Motzkin et al., 2014). Both grit and growth mindset are related to staving off distractions, whether it be in pursuit of a goal or learning in general.

Grit was related to positive functional connectivity between vStr and a medial prefrontal network. These medial prefrontal regions include the rACC and portions of the mPFC (Öngür et al., 2003), which project to the ventromedial striatum and are related to prediction of reward. Our findings, based on striatal connectivity, corroborate findings from a previous study of trait persistence in which the authors describe the elimination of the partial reinforcement extinction effect where behavior persists in the absence of reinforcement when lesions to the mPFC and vStr are present (Gusnard et al., 2003). These findings may be particularly relevant to grit, which is characterized by the long-term pursuit of a goal, when intermittent reinforcement may be absent. Further, top-down control of regions related to emotion and motivation, such as the vStr, may be modulated by regions of the PFC (Richard and Berridge, 2013). Of note, vStr connectivity with the right DLPFC remained significantly correlated with grit when regressing out growth mindset. Recent attempts to characterize lateralization of DLPFC activations in the Stroop task noted that the right DLPFC may upregulate cognitive

control in the context of conflict, thus reducing interference of irrelevant stimuli (Vanderhasselt et al., 2009), though it is important to note that these findings were not related to connectivity between the DLPFC and striatum. Additionally, grit was positively correlated with vStr connectivity to PCC, which may be related to choices involving delayed gratification (Weber and Huettel, 2008). Grit, therefore, may be characterized by a robust network of cognitive and affective control to persevere while maintaining focus on a delayed receipt of reward.

A greater growth mindset compared to grit was uniquely associated with dStr connectivity and cortical projections such as to the dACC and the DLPFC, which are shown to be critical to error-monitoring and concordant behavioral adaptation (Stevens et al., 2009). There is a small body of existing imaging literature, suggesting people with a growth mindset are efficient error monitors and are receptive to corrective feedback (Moser et al., 2011). In an event-related potential study, those with a fixed mindset exhibited a greater anterior prefrontal P3 response, or an emotional response to errors thought to be reflective of concerns about their performance compared to others (Mangels et al., 2006). Mangels et al. (2006) go on to suggest that holding a positive view of challenge, as seen in growth mindset, may in some part neutralize affective response to negative feedback. It is important to note that these previous studies examined neural activation while the current study focuses on connectivity and that neural connectivity does not imply the connected regions are more activated. However, the prior work helps to put our findings on functional covariance of spontaneous activity between striatum and cortical regions into perspective. When regressing out grit, growth mindset was more strongly correlated with connectivity between the vStr and left DLPFC. Attempts to differentiate the role of the left DLPFC in cognitive updating using the Stroop task suggest that the left DLPFC is selectively involved in task-switching and regulation of strategies when upcoming incongruent trials are forewarned (Vanderhasselt et al., 2009).

Though this paper is the first of its kind to explore similarities and differences of neural mechanisms of these two non-cognitive constructs, this study has a number of limitations. First, grit and growth mindset are measures that are validated in samples of adolescents, so behavioral measures were collected approximately 2 years after brain measures (in pre-adolescence) were collected. Second, the sample size is small. As more attention is brought to these skills in education, further validation in larger samples will be necessary in order to appropriately accommodate diverse populations before beginning to think about widespread translation to intervention.

We demonstrate that both grit and growth mindset show associations with cognitive-behavioral control networks. Intriguingly, they also demonstrate distinctively divergent networks. Ventral striatal networks involving the mPFC as well as the PCC highly correlated with grit and likely represent strategies for staving off distractions in the face of delayed reinforcement. However, growth mindset correlated networks included those implicated in regulation strategies and error-monitoring, such as seen in correlation with connectivity between dStr and the dACC and left DLPFC. This could be related to the awareness that updating and regulating learning strategies based on new information is critical to learning.

The knowledge gained from studies such as ours may help develop neurobiological models of non-cognitive skills relevant to education and related interventions. The new models can serve as an intermediate step of validating the brain basis of non-cognitive skills in order to better understand targeted

interventions and more generally, the development of skills such as grit and growth mindset. The models will also complement similar models of academic skills, such as for reading and math, that have attracted far more attention to date.

## Funding

F.H. was supported by the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) Grants K23HD054720 (PI: F. Hoeft), R01HD078351 (PI: F. Hoeft), R01HD044073 (PI: L. Cutting, Vanderbilt U), R01HD065794 (PI: K. Pugh, Haskins Labs), P01HD001994 (PI: J. Rueckl, Haskins Labs), the National Institute of Mental Health (NIMH) Grants R01MH104438 (PI: C. Wu Nordahl, UC Davis MIND Institute), R01MH103371 (PI: D. Amaral, UC Davis MIND Institute), the National Science Foundation (NSF) Grant NSF1540854 SL-CN (PI: A. Gazzaley), UCSF Dyslexia Center, UCSF Academic Senate Award, Bay Area Discovery Museum's Center for Childhood Creativity UCSF-CCC Neuroscience Fellowship (& Liebe Patterson), Dennis & Shannon Wong - DSEA '88 Foundation, and the Oak Foundation. J.M.B. was supported by Boston College Ignite Award. C.A.M. was supported by Childhood Center for Creativity (CCC) Neuroscience Fellowship.

## Acknowledgements

We would like to thank Natalie Tamburello for her background research and Roeland Hancock for his technological support.

## Supplementary data

Supplementary data are available at SCAN online.

Conflict of interest. None declared.

## References

- Aronson, J., Fried, C.B., Good, C. (2002). Reducing the effects of stereotype threat on African American college students by shaping theories of intelligence. *Journal of Experimental Social Psychology*, **38**(2), 113–25.
- Ashburner, J. (2007). A fast diffeomorphic image registration algorithm. *Neuroimage*, **38**(1), 95–113.
- Averbeck, B.B., Lehman, J., Jacobson, M., Haber, S.N. (2014). Estimates of projection overlap and zones of convergence within frontal-striatal circuits. *Journal of Neuroscience*, **34**(29), 9497–505.
- Behzadi, Y., Restom, K., Liu, J., Liu, T.T. (2007). A component based noise correction method (CompCor) for BOLD and perfusion based fMRI. *Neuroimage*, **37**(1), 90–101.
- Blackwell, L.S., Trzesniewski, K.H., Dweck, C.S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: a longitudinal study and an intervention. *Child Development*, **78**(1), 246–63.
- Burnette, J.L., O'Boyle, E.H., VanEpps, E.M., Pollack, J.M., Finkel, E.J. (2013). Mind-sets matter: a meta-analytic review of implicit theories and self-regulation. *Psychological Bulletin*, **139**(3), 655–701.
- Cooper, J.C., Dunne, S., Furey, T., O'Doherty, J.P. (2012). Human dorsal striatum encodes prediction errors during



- observational learning of instrumental actions. *Journal of Cognitive Neuroscience*, **24**(1), 106–18.
- Cox, R.W. (1996). AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. *Computers and Biomedical Research*, **29**(3), 162–73.
- Cunha, F., Heckman, J.J. (2008). Formulating, identifying and estimating the technology of cognitive and noncognitive skill formation. *The Journal of Human Resources*, **43**(4), 738–82.
- Duckworth, A.L., Eskreis-Winkler, L. (2013). Grit. *Observer* **26**(4), 1–3.
- Duckworth, A.L., Peterson, C., Matthews, M.D., Kelly, D.R. (2007). Grit: perseverance and passion for long-term goals. *Journal of Personality and Social Psychology*, **92**(6), 1087–101.
- Duckworth, A.L., Quinn, P.D. (2009). Development and validation of the short grit scale (grit-s). *Journal of Personality Assessment*, **91**(2), 166–74.
- Dweck, C.S. (1999). *Self-Theories: Their Role in Motivation, Personality, and Development*. Philadelphia: Psychol. Press.
- Dweck, C.S. (2006). *Mindset: The New Psychology of Success*, 1st edn. New York: Random House.
- Eskreis-Winkler, L., Shulman, E.P., Beal, S.A., Duckworth, A.L. (2014). The grit effect: predicting retention in the military, the workplace, school and marriage. *Frontiers in Psychology*, **5**, 36.
- Glover, G.H., Law, C.S. (2001). Spiral-in/out BOLD fMRI for increased SNR and reduced susceptibility artifacts. *Magnetic Resonance in Medicine* **46**, 515–22.
- Good, C., Aronson, J., Inzlicht, M. (2003). Improving adolescents' standardized test performance: an intervention to reduce the effects of stereotype threat. *Journal of Applied Developmental Psychology*, **24**(6), 645–62.
- Grant, H., Dweck, C.S. (2003). Clarifying achievement goals and their impact. *Journal of Personality and Social Psychology*, **85**(3), 541–53.
- Gusnard, D.A., Ollinger, J.M., Shulman, G.L., et al. (2003). Persistence and brain circuitry. *Proceedings of the National Academy of Sciences of the United States of America*, **100**(6), 3479–84.
- Heckman, J.J., Rubinstein, Y. (2001). The importance of noncognitive skills: lessons from the GED testing program. *The American Economic Review*, **91**(2), 145–9.
- Liljeholm, M., O'Doherty, J.P. (2012). Contributions of the striatum to learning, motivation, and performance: an associative account. *Trends in Cognitive Sciences*, **16**(9), 467–75.
- Mangels, J.A., Butterfield, B., Lamb, J., Good, C., Dweck, C.S. (2006). Why do beliefs about intelligence influence learning success? A social cognitive neuroscience model. *Social Cognitive and Affective Neuroscience*, **1**(2), 75–86.
- Mazaika, P.K., Hoeft, F., Glover, G.H., Reiss, A.L. (2009). Methods and Software for fMRI Analysis of Clinical Subjects. *Neuroimage* **47**, S58.
- Moser, J.S., Schroder, H.S., Heeter, C., Moran, T.P., Lee, Y.H. (2011). Mind your errors: evidence for a neural mechanism linking growth mind-set to adaptive posterror adjustments. *Psychological Science*, **22**(12), 1484–9.
- Motzkin, J.C., Baskin-Sommers, A., Newman, J.P., Kiehl, K.A., Koenigs, M. (2014). Neural correlates of substance abuse: reduced functional connectivity between areas underlying reward and cognitive control. *Human Brain Mapping*, **35**(9), 4282–92.
- O'Doherty, J., Dayan, P., Schultz, J., Deichmann, R., Friston, K., Dolan, R.J. (2004). Dissociable roles of ventral and dorsal striatum in instrumental conditioning. *Science*, **304**(5669), 452–4.
- Öngür, D., Ferry, A.T., Price, J.L. (2003). Architectonic subdivision of the human orbital and medial prefrontal cortex. *The Journal of Comparative Neurology*, **460**(3), 425–49.
- Pauli, W.M., O'Reilly, B.C., Yarkoni, T., Wager, T.D. (2016). Regional specialization within the human striatum for diverse psychological functions. *Proceedings of the National Academy of Sciences of the United States of America*, **113**(7), 1907–12.
- Perkins-Gough, D. (2013). The significance of GRIT: a conversation with Angela Lee Duckworth. *Educational Leadership*, **71**(1), 14–20.
- Richard, J.M., Berridge, K.C. (2013). Prefrontal cortex modulates desire and dread generated by nucleus accumbens glutamate disruption. *Biological Psychiatry*, **73**(4), 360–70.
- Shohamy, D. (2011). Learning and motivation in the human striatum. *Current Opinion in Neurobiology*, **21**(3), 408–14.
- Stevens, M.C., Kiehl, K.A., Pearlson, G.D., Calhoun, V.D. (2009). Brain network dynamics during error commission. *Human Brain Mapping*, **30**(1), 24–37.
- van den Heuvel, M.P., Hulshoff Pol, H.E. (2010). Exploring the brain network: a review on resting-state fMRI functional connectivity. *European Neuropsychopharmacology*, **20**(8), 519–34.
- Vanderhasselt, M.A., De Raedt, R., Baeken, C. (2009). Dorsolateral prefrontal cortex and Stroop performance: tackling the lateralization. *Psychonomic Bulletin and Review*, **16**(3), 609–12.
- Voorn, P., Vanderschuren, L.J., Groenewegen, H.J., Robbins, T.W., Pennartz, C.M. (2004). Putting a spin on the dorsal-ventral divide of the striatum. *Trends in Neuroscience*, **27**(8), 468–74.
- Weber, B.J., Huettel, S.A. (2008). The neural substrates of probabilistic and intertemporal decision making. *Brain Research*, **1234**, 104–15.
- West, M.R., K, M.A., Finn, A.S., Duckworth, A.L., Gabrieli, C.F.O., Gabrieli, J.D.E. (2014). *Promise and paradox: measuring students' non-cognitive skills and the impact of schooling*. *Educational Evaluation and Policy Analysis*, **38**(1), 148–70.
- Whitfield-Gabrieli, S., Nieto-Castanon, A. (2012). Conn: a functional connectivity toolbox for correlated and anticorrelated brain networks. *Brain Connection*, **2**(3), 125–41.

## Supplementary Online Material

### METHODS

#### *Participants*

Twenty healthy children (9 females, average age 11.2) were included in this study (see **Table S1** for demographic information) from a larger study with a primary focus of examining the neural pathways important for academic achievement in native-English speakers in the United States. A comprehensive socio-emotional survey was administered, on average, approximately two years following collection of structural and resting state functional MRI scans (mean 11.22 years, SD 2.08 years). Participants were offered monetary incentive for completing a comprehensive socio-emotional survey. Of the original participants, 30 participants completed the online survey. Of those 30, a subset of 21 participants had both resting state and structural scans (used for registration and removal of noise from white matter and cerebral spinal fluid) available. Further, one participant was excluded due to excessive motion in their resting state scan (2.27 mm mean framewise displacement).

#### *Environmental, Behavioral and Socio-Emotional Measures*

Parental measures of socio-economic status (SES) and cognitive proficiency were collected at the onset of the original study (**Table S1**). These measures are reported to evaluate the potential effect that home environment may have on our socio-emotional measures of interest: grit and mindset. SES measures included parent-reported income and maternal and paternal years of education, as education is strongly representative of SES (e.g. Smith and Graham, 1995). Parental measures of performance, verbal, and full-scale intelligence were evaluated using the Wechsler Abbreviated Intelligence Scale (The Psychological Corporation, 1999).

Participant handedness was also measured at the onset of the original study using the Edinburgh Handedness Inventory (Oldfield, 1971). WASI or Woodcock Johnson III Test of Cognitive Abilities- Revised Normative Update-- Brief Intellectual Ability composite score (Verbal Comprehension, Concept Formation, and Visual Matching) was used to evaluate participant IQ (The Psychological Corporation, 1999; Woodcock et al., 2001). Duckworth's Grit Short Scale (Grit-S) is 8 items (Duckworth and Quinn, 2009) has an internal consistency of alphas ranging from 0.60 to 0.78 and test-retest stability of  $r=0.68$ . Mindset, measured by Theory of Intelligence in the Psychological Causes of Student Achievement Measures (Blackwell et al., 2007), has a test-retest reliability of 0.77 and an internal reliability of 0.78 (Blackwell et al., 2007). In addition to the main variables of interest, grit and mindset, additional social and emotional



measures were collected due to their known relationships to grit and/or mindset. The entirety of Psychological Causes of Student Achievement Measures was collected (Blackwell et al., 2007) as well as Children's Self Efficacy Scale's Self-Regulated Learning (Bandura, 2006). The relationships of grit and intelligence beliefs with other socio-emotional, demographic, and SES measures in our sample were investigated using correlation analyses (**Table S2**).

## RESULTS

### *Behavioral correlations*

Descriptive statistics of demographic and behavioral variables are presented in **Table S1**. In addition, similarities and differences between grit and intelligence beliefs were observed in a series of correlational analyses. These results are presented in **Table S2**. Grit and intelligence beliefs showed small but non-significant correlation, in line with prior research ( $r=0.34$ ,  $p=0.14$ ).

In concordance with extant findings, an incremental theory of intelligence (greater growth mindset) correlated with greater Performance Learning Goals ( $r=0.496$ ,  $p=0.026$ ), Effort Beliefs ( $r=0.535$ ,  $p=0.015$ ), Low Helplessness Attributions ( $r=0.506$ ,  $p=0.023$ ), and Positive Study Strategies ( $r=0.543$ ,  $p=0.013$ ) (**Table S2**; (Blackwell et al., 2007)). Incremental theorists (those with a growth mindset) have increased self-efficacy over those who believe intelligence is fixed (Martocchio, 1994). In line with this, greater intelligence beliefs showed non-significant but positive correlation with Bandura's Children's Self-Efficacy scale Self-Regulated Learning ( $r=0.305$ ,  $p=0.191$ ).

Grit has been shown to be related to self-regulatory processes such as self-control and conscientiousness (Duckworth et al., 2007), study strategies, such as deliberate practice and being quizzed in Spelling Bee competitors (Duckworth et al., 2011) and is comprised of overall effort and consistency of interest (Von Culin et al., 2014). Likewise, our sample showed corresponding correlations between Measures of Psychological Causes of Student Achievement Effort Goals ( $r=0.477$ ,  $p=0.034$ ) and Beliefs ( $r=0.569$ ,  $p=0.009$ ), Study Strategies ( $r=0.674$ ,  $p=0.001$ ) (Blackwell et al., 2007) and Self-Efficacy Scales Self-Regulated Learning ( $r=0.585$ ,  $p=0.007$ ) (Bandura, 2006).

### *Imaging correlations with two grit factors*

The grit scale used in the current study has a two-factor structure: consistency of interest and perseverance of effort. When the resting state connectivity from the dorsal striatum seed was correlated with these two factors separately, there were no significant clusters, similar to when a single grit score was used. When the resting-state network from the ventral striatal seed was correlated with each factor separately, the clusters found when using a single factor were

essentially significant in one factor or the other. More specifically, Factor 1 (consistency of interest) was positively correlated with vStr connectivity with rACC and PCC, which is consistent with rACC's well-documented role in affective response (Devinsky et al., 1995). On the other hand, Factor 2 (perseverance of effort) was positively correlated with vStr connectivity with mPFC, which indicates the importance of the PFC in maintaining and regulating goal-directed activities (Ridderinkhof et al., 2004). Taken together, the clusters from the simple correlation analyses with the two grit factors were similar to when a single grit score was used, indicating that both factors contributed to the grit-related results.

## REFERENCES

- Bandura (2006) Guide for Constructin Self-Efficacy Scales. In: *Self-efficacy Beliefs of Adolescents*, pp 307–337. IAP.
- Blackwell LS, Trzesniewski KH, Dweck CS (2007) Implicit Theories of Intelligence Predict Achievement Across an Adolescent Transition: A Longitudinal Study and an Intervention. *Child Dev* 78:246–263.
- Devinsky O, Morrell MJ, Vogt BA (1995) Contributions of anterior cingulate cortex to behaviour. *Brain* 118: 279-306
- Duckworth AL, Kirby TA, Tsukayama E, Berstein H, Ericsson KA (2011) Deliberate Practice Spells Success Why Grittier Competitors Triumph at the National Spelling Bee. *Soc Psychol Personal Sci* 2:174–181.
- Duckworth AL, Peterson C, Matthews MD, Kelly DR (2007) Grit: Perseverance and passion for long-term goals. *J Pers Soc Psychol* 92:1087–1101.
- Duckworth AL, Quinn PD (2009) Development and Validation of the Short Grit Scale (Grit–S). *J Pers Assess* 91:166–174.
- Martocchio JJ (1994) Effects of conceptions of ability on anxiety, self-efficacy, and learning in training. *J Appl Psychol* 79:819–825.
- Oldfield RC (1971) The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9:97–113.
- Ridderinkhof KR, Ullsperger M, Crone EA, Nieuwenhuis S. (2004) The role of the medial frontal cortex in cognitive control. *Science* 306: 443-447
- Smith TE, Graham PB (1995) Socioeconomic Stratification in Family Research. *J Marriage Fam* 57:930–940.

The Psychological Corporation (1999) Wechsler Abbreviated Scale of Intelligence. San Antonio: Harcourt Brace & Co.

Von Culin KR, Tsukayama E, Duckworth AL (2014) Unpacking grit: Motivational correlates of perseverance and passion for long-term goals. *J Posit Psychol* 9:306–312.

Woodcock RW, McGrew KS, Mather N, Schrank FA (2001) Woodcock-Johnson III (WJ-III). Itasca, IL: Riverside.

**Table S1. Demographics and Behavioral Descriptives**

Measure	Subtest	Description (Higher score means...)	Mean (SD)	Range (min,max)
Age at survey (years)			11.22(2.08)	8.58(7.91,16.49)
Age at scan (years)			9.32(2.12)	8.59(5.84,14.43)
Time between scan & survey			1.90(0.32)	1.06(1.12,2.18)
Gender			9 females, 11 males	
Handedness			3 left-handed	
Income		Family combined yearly income	\$244,736.84(\$205,998.61)	\$630,000.00(\$70,000.00-\$700,000.00)
Maternal education years		Measured from Kindergarten onwards	16.80(1.91)	7.00(14.00,21.00)
Paternal education years		Measured from Kindergarten onwards	16.45(1.82)	6.00(14.00,20.00)
Participant IQ		Wechsler Abbreviated Scale of Intelligence-Revised: Full-Scale Intelligence Quotient OR Woodcock Johnson III Test of Cognitive Abilities-Revised Normative Update, Brief Intellectual Ability composite score	114.75(12.41)	49.00(90.00,139.00)
Grit		Student tends to have great interest in and put much effort into long term goals, even if they are very challenging	3.28(0.72)	2.38(2.38,4.75)
Psychological Causes of Student Achievement	Mindset (Theory of Intelligence)	Individual tends to believe that intelligence is malleable (e.g. with hard work, effort, studying, etc.)	4.49(0.92)	3.50(2.50,6.00)
	Performance Approach Goals	Individual tends to prefer performing well as a way of demonstrating academic ability, including when performance comes at the expense of learning	4.53(0.70)	2.67(3.33,6.00)
	Performance Avoid Failure Goals	Individual works to avoid performing poorly as a way of demonstrating their academic ability	3.68(1.25)	4.67(1.00,5.67)
	Performance Learning Goals	Individual tends to value the act of learning, even if it conflicts with short-term academic performance	4.18(1.08)	3.67(2.33,6.00)



	Effort Minimization Goals	Individual tends to value spending extra time and effort on school work	3.46(1.28)	4.25(1.00,5.25)
	Effort Beliefs	Individual tends to believe that effort leads to positive outcomes	4.62(0.63)	2.56(3.11,5.67)
	Response to Failure (helpless vs. mastery orientation)	Individual tends to display more positive emotions in the face of failure (e.g. feel motivated), and would tend to engage in positive, effort-based strategies next time	4.53(0.47)	1.93(3.53,5.47)
	Importance of Academic Performance and Effort	Individual tends to identify with the belief that academic performance and spending time on school work is important	5.19(0.85)	2.75(3.25,6.00)
	Test Anxiety	Individual does not tend to identify with having test anxiety, worrying about tests, feeling very nervous, or thinking they are doing poorly on a test	4.37(1.14)	3.60(2.40,6.00)
	Importance of Language Arts	Individual tends to believe that English/Language Arts is a very important subject	4.81(0.74)	2.60(2.60,3.40)
	Study Strategies	Individual tends to believe that putting ideas in own words, copying notes to aide memory, practicing saying facts, writing outlines, asking self questions while studying, and looking over notes are important strategies to learning	3.63(0.86)	2.85(2.46,5.31)
Self-Efficacy Scales	Self-Regulated Learning	Student tends to have greater certainty that s/he can engage in self-directed strategies to enhance learning and academic success, such as: finishing assignments on time, taking good notes during class, using library resources, and concentrating on school subjects during class	77.30(16.78)	61.00(39.00,100.00)

**Table S2. Behavioral Correlations with Grit and Mindset**

<b>Measure</b>	<b>Subtest</b>	<b>Correlation with Grit: Pearson Correlation ( R), Significance (p)</b>	<b>Correlation with Mindset: Pearson Correlation ( R), Significance (p)</b>
Age at survey (years)		-0.261, 0.267	0.364, 0.115
Age at scan (years)		-0.309, 0.184	0.373, 0.105
Gender		0.031, 0.895	-0.271, 0.247
Handedness		0.219, 0.353	0.516, 0.020
Income <sup>a</sup> N=19		-0.272, 0.260	0.183, 0.455
Maternal education years		-0.077, 0.747	0.014, 0.953
Paternal education years		0.301, 0.197	0.055, 0.819
Participant IQ <sup>c</sup>		0.064, 0.789	-0.110, 0.645
Grit		N/A	0.339, 0.144
Psychological Causes of Student Achievement	Mindset (Intelligence Beliefs)	0.339, 0.144	N/A
	Performance Approach Goals	0.113, 0.636	0.372, 0.106
	Performance Avoid Failure Goals	-0.293, 0.210	-0.212, 0.369
	Performance Learning Goals	0.392, 0.088	0.496, 0.026
	Effort Minimization Goals	0.477, 0.034	0.463, 0.040
	Effort Beliefs	0.569, 0.009	0.535, 0.015
	Response to Failure (helpless vs. mastery orientation)	0.559, 0.010	0.506, 0.023
	Importance of Academic Performance and Effort	0.450, 0.046	0.477, 0.033
	Test Anxiety	0.554, 0.011	0.231, 0.328
	Study Strategies	0.674, 0.001	0.543, 0.013
Self-Efficacy Scales	Self-Regulated Learning	0.585, 0.007	0.305, 0.191

**Table S3. Functional Connectivity Correlation Between Striatal Seeds and Grit/Mindset (Simple Correlation)**

		<b>Simple Correlation Grit</b>					
<b>Seed Region</b>	<b>Correlation Direction</b>	<b>MNI Coordinates</b>			<b>Cluster Size (voxels)</b>	<b>Peak T Values</b>	<b>Approximate Location</b>
		<b>x</b>	<b>y</b>	<b>z</b>			
Dorsal Striatum	Negative	-14	18	6	455	4.69	A cluster including left caudate and left thalamus
		-18	-12	10		3.06	
		-32	6	20		2.77	
		-50	-56	18	543	4.26	A cluster that spans the left angular gyrus and left lateral occipital cortex
		-46	-70	22		2.7	
Ventral Striatum	Positive	0	36	24	3256	5.21	A cluster spanning from the medial prefrontal cortex to the rostral anterior cingulate cortex to the dorsal anterior cingulate cortex, including a segment that reaches the right frontal pole and extends bilaterally to the dorsolateral prefrontal cortex
		10	44	20		5.11	
		12	36	26		4.65	
		12	-22	32	1232	4.85	Posterior cingulate cortex
		18	-42	46		3.99	
-16	-32	28	3.52				
		<b>Simple Correlation Mindset</b>					
		<b>MNI Coordinates</b>			<b>Cluster Size (voxels)</b>	<b>Peak T Values</b>	<b>Approximate Location</b>
		<b>x</b>	<b>y</b>	<b>z</b>			
Dorsal Striatum	Positive	-44	38	22	932	4.18	Left Dorsolateral Prefrontal Cortex
		-32	36	26		4.12	
		-32	36	10		2.45	
		16	8	42	548	4.06	Dorsal anterior cingulate cortex, Middle cingulate cortex
		2	22	32		3.38	
		0	22	40		3.23	
		-4	-68	-18	930	4.05	Cerebellum
		-10	-52	-20		3.42	
		18	-74	-26		3.07	
		-16	-70	-46	623	3.42	Cerebellum
-4	-72	-52	3.42				
-26	-74	-34	3.38				
Dorsal Striatum	Negative	24	-48	18	752	4.21	A cluster including the precuneus
		0	-60	24		3.43	

Ventral Striatum	Positive	-10 -70 -26	2334	6.46	Cerebellum	
		-4 -72 -18				
		14 -72 -24				
		52 0 24	2310	4.68		
		66 4 8				
		42 -14 34				
		38 46 16	506	4.53		Right Dorsolateral Prefrontal Cortex
		52 48 10				
		-32 44 20	609	4.23		Left Dorsolateral Prefrontal Cortex
		-34 34 8				
-56 0 18	842	3.96	Left Precentral Gyrus, Opercular Cortex			
-50 8 0						
-40 -8 20						

Table S4. Functional Connectivity Correlation Between Striatal Seeds and Grit/Mindset

		Partial Correlation Grit Regress Mindset					
Seed Region	Correlation Direction	MNI Coordinates			Cluster Size (voxels)	Peak T Values	Approximate Location
		x	y	z			
Dorsal Striatum	Negative	-16	16	8	793	5.3	A cluster including the left caudate
		-26	14	6			
		-32	6	20			
Ventral Striatum	Positive	16	-24	34	843	4.98	Posterior cingulate cortex
		18	-42	46			
		8	-40	50			
	Positive	0	36	24	2456	4.68	A cluster spanning from the medial prefrontal cortex to the rostral anterior cingulate cortex to the dorsal anterior cingulate cortex, including a segment that reaches the right frontal pole
		10	44	20			
		-16	48	0			
Negative	Negative	44	-68	-30	1208	4.09	A large cluster spanning the cerebellum
		4	-82	-26			
		48	-54	-26			



		Partial Correlation Mindset Regress Grit			
Dorsal Striatum	Positive	40 -10 32	1067	5.26	Right Middle Frontal Gyrus, Precentral Gyrus, Superior Frontal Gyrus
		38 0 60		3.51	
		22 8 68		3.39	
		-32 38 24	1041	5.04	Left Dorsolateral Prefrontal Cortex
		-44 38 22		4.51	
		-32 36 10		2.67	
		-18 -70 -44	887	4.29	Cerebellum
		-26 -74 -34		3.73	
		-2 -70 -52		3.45	
		8 18 30	1004	4.15	Dorsal anterior cingulate cortex, Middle cingulate cortex
		14 8 44		3.96	
		0 20 40		3.77	
		0 -68 -16	1481	4	Cerebellum
		-8 -54 -22		3.98	
32 -62 -28	3.77				
-56 2 18	842	2.95	Left Precentral Gyrus		
-64 -30 20		2.89			
-50 -6 8		2.84			
24 -46 18	838	4.94	A cluster including the precuneus		
14 -32 18		3.82			
26 -24 20		3.03			
Ventral Striatum	Positive	-10 -70 -26	3409	6.35	Cerebellum
		-2 -74 -18		6	
		16 -72 -24		5.01	
		40 -10 32	2501	4.79	A cluster spanning the right precentral and postcentral gyrus
		52 0 24		4.52	
		42 -6 22		4.36	
		-44 -16 44	1979	4.46	Left Precentral Gyrus, Opercular Cortex
		-48 -6 16		3.95	
		-38 -10 20		3.89	
		-32 44 18	529	3.85	Left Dorsolateral Prefrontal Cortex
-32 32 10	2.83				