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.

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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

Measure	Subtest	Correlation with Grit: Pearson Correlation (R), Significance (p)	Correlation with Mindset: Pearson Correlation (R), Significance (p)
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[a 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[c]		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)

		Simple Correlation Grit					
		MNI Coordinates					
Seed Region	**Correlation Direction**	**x**	**y**	**z**	**Cluster Size (voxels)**	**Peak T Values**	**Approximate Location**
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	
		Simple Correlation Mindset					
		MNI Coordinates			**Cluster Size (voxels)**	**Peak T Values**	**Approximate Location**
		x	**y**	**z**			
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		5.74	
		14	-72	-24		4.99	
		52	0	24	2310	4.68	A cluster spanning the right precentral and postcentral gyrus
		66	4	8		4.16	
		42	-14	34		3.8	
		38	46	16	506	4.53	Right Dorsolateral Prefrontal Cortex
		52	48	10		3.51	
		-32	44	20	609	4.23	Left Dorsolateral Prefrontal Cortex
		-34	34	8		2.92	
		-56	0	18	842	3.96	Left Precentral Gyrus, Opercular Cortex
		-50	8	0		3.69	
		-40	-8	20		3.22	

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

		Partial Correlation Grit Regress Mindset					
		MNI Coordinates					
Seed Region	**Correlation Direction**	**x**	**y**	**z**	**Cluster Size (voxels)**	**Peak T Values**	**Approximate Location**
Dorsal Striatum	Negative	-16	16	8	793	5.3	A cluster including the left caudate
		-26	14	6		4.07	
		-32	6	20		3.21	
Ventral Striatum	Positive	16	-24	34	843	4.98	Posterior cingulate cortex
		18	-42	46		3.72	
		8	-40	50		2.8	
		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		4.59	
		-16	48	0		4.52	
	Negative	44	-68	-30	1208	4.09	A large cluster spanning the cerebellum
		4	-82	-26		3.88	
		48	-54	-26		3.62	

		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	
	Negative	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	