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Inhibitory Control Predicts Academic Performance Beyond Fluid Intelligence and Processing Speed in English-Immersed Chinese High Schoolers

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Abstract

Investigation of the relationship between cognitive function and academic performance has recently pivoted from differences in intelligence to executive function. To date, these studies have focused disproportionately on samples recruited from Western countries, despite evidence in support of cultural differences in these putative relationships. To address this gap, the present study investigated whether differences in inhibitory and/or attentional control could predict academic performance in a sample of Chinese adolescents (*n*=42). Participants reported on demographic details and completed both the Simon task and Attention Network Test. Data were analyzed using multiple linear regression controlling for gender, age, SES, English language proficiency, processing speed, and fluid intelligence. Results showed that one index of inhibitory control derived from flanker task performance explained a significant amount of unique variance in academic performance. Our findings provide evidence that executive function, specifically inhibitory control, plays a significant role in academic performance.

Keywords: academic performance; inhibitory control; executive function; fluid intelligence; high school students

Introduction

There continues to be considerable interest in identifying the factors underlying observed differences in academic performance, "the extent to which a student, teacher or institution has achieved their educational goals" (Ward et al., 1996). Much of this interest stems from the expressed goal of wanting to place students from heterogenous populations in appropriate educational programs that will maximize their academic development (Helal et al., 2018). Over the last decade, the previous focus on intelligence has shifted towards investigation of dissociable components of executive function (Cortés Pascual et al., 2019). These components, including inhibition, shifting, and updating, are thought to control and coordinate cognitive subprocesses in support of goal achievement (Miyake et al., 2000). Executive functions are essential for success across a diverse range of domains including preparation for and performance during schooling (Diamond, 2013). Currently, there are inconsistent findings regarding which component(s) of executive function are most associated with academic performance, and whether these associations are modified by age, socioeconomic status (SES), or other variables. For these reasons, there is a need to further explore the association between executive function and academic performance.

Executive function is comprised of at least three related but separable dimensions (Miyake et al., 2000). Each dimension is thought to control a range of cognitive abilities, operating through attentional functions in a manner that is goal directed (Braver, 2012). *Inhibitory control*, sometimes called inhibition, supports the ability inhibit a prepotent response or ignore irrelevant or distracting information (i.e., interference suppression). *Shifting*, sometimes referred to as task switching or set shifting, underlies our ability to switch between different tasks or mental sets. Finally, *updating*, which includes monitoring, is the ability to monitor and edit representations held in working memory. Although more recent research has identified considerable unity across the separate dimensions of executive function (Friedman & Miyake, 2017), the relationship with academic performance is generally investigated from the separate dimensions perspective (St Clair-Thompson & Gathercole, 2006). Findings support that this relationship differs based on the specific dimension of executive function, academic performance discipline, and age group studied (Cortés Pascual et al., 2019). Across these previous studies, working memory, a component of updating, has been the most widely studied aspect of executive function.

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Investigations of the relationship between academic performance and executive function in adolescent samples outside of Western countries are fairly limited. Limited previous studies conducted in China have reported mixed, culturally-specific findings regarding this putative relationship across the multiple dimensions of executive function, including attentional control (e.g., Lan et al., 2011; Thorell et al., 2013). Considering the disproportionate focus on studies of working memory in Western samples, the relationship between other dimensions of executive function and academic performance merits further investigation in more diverse, under-studied samples.

To address these gaps in the literature, the present study aimed to investigate the relationship between academic performance and two understudied dimensions of executive function (i.e., inhibitory and attentional control) in a non-Western sample of international high school students in Southern China. Specifically, as there is considerable evidence supporting a relationship between academic performance and gender, age, SES, fluid intelligence, and processing speed (e.g., Lee & Shute, 2010; Richardson et al., 2012; Rohde & Thompson, 2007), we investigated whether inhibitory and/or attentional control explained additional variance in academic performance when controlling for these other variables. Additionally, because academic performance was assessed entirely in English at the school from which our data were collected, we also controlled for self-reported English proficiency in our model. The inclusion of these variables during modeling also allowed us to control for their reported impact on behavioral task performance (e.g., Alves et al., 2016; Anderson, 2002; Noble et al., 2007; Privitera et al., 2022).

Methods

Participants

A sample of 42 Mandarin-English speaking bilingual high school students (32 females) were recruited from a private high school in Shenzhen, China. The average age of participating students was 16.21 years (*SD* = 1.60; 13 – 19 years). Students were all enrolled full time in a British curriculum high school where English was the primary language of instruction and assessment. This study was approved by the Human Research Ethics Committee of the University of Hong Kong (#EA200010). Informed consent was obtained from both parents and students prior to inclusion in the study. All students received community service hours toward their graduation requirement in exchange for participation.

Questionnaires and Task

Measure of Academic Performance Participating students completed courses across a wide range of disciplines during their high school study including English, mathematics, social science, and laboratory science. While the specific courses completed differed for each student, it was not the case that any student was only taking courses in any one discipline. For this reason, overall grade point average (GPA), reported out of 4 total points, was used as a measure of academic performance. The use of overall GPA provides a more general measure of academic performance, avoiding the limits associated with focusing on performance in any particular discipline. Current GPA scores for each participant were obtained from our partner school's academic affairs office.

Measure of Fluid Intelligence A wide range of pencil-and-paper and computer-based instruments exist for assessing differences in fluid intelligence. As part of their initial screening after acceptance, students at our partner school completed the Cognitive Abilities Test (CAT 4th Edition, G.L. Assessment 2016). This standardized instrument is comprised of four separate subtests designed to measure verbal, non-verbal, quantitative, and spatial reasoning. Test items included in the non-verbal reasoning subtest are similar to those found in widely-used instruments for assessing fluid intelligence such as Raven's Progressive Matrices (Raven & Court, 1938). Most importantly considering that our sample is drawn from a bilingual population, the results of the non-verbal reasoning subtest are not confounded by language. For these reasons, student scores on the CAT4 non-verbal reasoning subtest were used as a measure for fluid intelligence in the present study. CAT4 scores are reported as standard age scores with an average of 100 based on a normative, age-matched dataset collected in the United Kingdom. The accepted mark range for each subtest is 50-160 points.

Additional Background Measures Although our sample was drawn from a socioeconomically similar population of students, we further assessed differences in SES by asking students to report on family education level (Wermelinger et al., 2017). Additionally, because the primary language of instruction and assessment at our partner school was English, differences in academic performance could be attributed to differences English language proficiency. To address this, students completed the Language History Questionnaire (LHQ-3) (Li et al., 2020), and aggregate scores for English language proficiency were included in our analyses. Despite criticism (Zell & Krizan, 2014), self-report measures of language proficiency have been found to correlate with objective measures (Gollan et al., 2011; Jia et al., 2002; Li et al., 2020; Marian et al., 2007; Schrauf, 2009), with comparable results reported when either measure is used (Zahodne et al., 2014).

Measures of Cognitive Functioning Processing speed and executive function measures were derived from behavioral task performance. Participants completed both the two-color Simon task (Bialystok et al., 2004; Privitera et al., 2022) and the Attention Network Test (ANT; Fan et al., 2002). For the Simon task, a fixation cross (black; 2.54 cm line; .254 cm thick) was presented on a white background for 300 ms at the start of each trial. Next, a blue or brown square target stimulus (2.54 X 2.54 cm) appeared to the left, right, or directly over the previous location of the central fixation cross. Based only on the color of the target stimulus, participants were instructed to press either the Q or P key on a computer keyboard with their left or right index finger, respectively. Stimuli remained on screen until a response was given, followed by a blank screen for 500 ms. In total, 6 practice trials with feedback and 42 experimental trials without feedback were presented randomly, with each color and position combination presented in equal proportion. Color key mapping was counterbalanced across participants. Conditions of the ANT followed those described in the original work (Fan et al., 2002), with the exception of trial stimuli remaining on screen until a response was given. The task included 24 practice trials with feedback and 288 experimental trials without feedback with all cue (i.e., no cue, center cue, double cue, and spatial cue) and congruency conditions (i.e., congruent, incongruent, and neutral) presented randomly in equal proportion.

Separate, task-specific indices for processing speed and two dimensions of executive function were derived from Simon and ANT performance. *Processing speed* was operationalized as average reaction time (RT) on neutral trials for the Simon task, or neutral, no cue trials on the ANT. These trials were selected because they present stimuli without additional conflicting or facilitating cues, providing a pure measure of baseline processing speed. There is debate surrounding which method is most appropriate for calculating an index of *inhibitory control* using data collected from behavioral tasks. Traditionally, the average RT for congruent trials is subtracted from the average for incongruent trials (henceforth called IC^{I-C}). However, some argue that the presentation of congruent trials (e.g., non-target flanker arrows pointing in the same direction as the target arrow on a flanker trial) results in a facilitatory effect, reducing the time needed in order to give a response. By this argument, congruent trials are not a true baseline condition, and are therefore inappropriate to use in the calculation of this index. As an alternative in response to the facilitation issue, this index is calculated by subtracting the average RT for neutral trials, thought to measure general processing speed, from the average for incongruent trials (henceforth called IC^{I-N}). In both calculations, *larger* resulting values correspond to *worse* inhibitory control. In response to this debate, we calculated both indices for inhibitory control and included each as a predictor in separate regression models.

Attentional control was operationalized as three separate indices of attentional network efficiency, calculated for each participant following guidelines published in the original ANT research (Fan et al., 2002). *Alerting network efficiency* was calculated by subtracting the average RT of the double cue trials from the average RT of the no cue trials. An additional index for alerting network efficiency, subtracting the average RT of the center cue trials from the average RT of the no cue trials, has also been proposed (Fan et al., 2005), and was calculated for all participants. *Orienting network efficiency* was calculated by subtracting the average RT of the spatial cue trials from the average RT of the center cue trials. For both alerting and orienting network efficiency indices, *higher* values correspond to *more efficient* attentional network function. All indices of cognitive functioning were calculated using RT data from correct trials only. Data were further trimmed to remove trials with RTs shorter than 150 ms, and longer than 2.5 SD above the average RT. Data trimming was performed separately for each congruency condition (i.e., congruent, incongruent, and neutral).

General Administration Procedures

Due to the limitations placed on in-person data collection at schools in Mainland China because of the ongoing COVID-19 pandemic, all data were collected using the Gorilla online experiment builder (Anwyl-Irvine et al., 2020). Behavioral data collected using online platforms is of comparable quality to data collected in a laboratory setting, with previous work replicating classic behavioral effects including those reported on the Simon and flanker tasks (Anwyl-Irvine et al., 2020; Crump et al., 2013; Jylkkä et al., 2017; Privitera et al., 2022). All participants first gave informed consent, then reported on basic demographic information and completed the LHQ-3, followed by either the Simon task or ANT with task order counterbalanced across participants.

Statistical Analysis

All statistical analyses were performed using jamovi (The jamovi project, 2020). Jamovi is free to use statistical software capable of performing a number of commonly used parametric and non-parametric analyses (Şahin & Aybek, 2019). Correlations were initially used to identify the strength and nature of relationship between academic performance and predictor variables. Linear regression was used in order to identify the variance in academic performance explained by separate indices of inhibitory or attentional control individually. Finally, multiple linear regression was used to identify the unique variance in academic performance explained by these measures while controlling for differences in gender, age, SES, English language proficiency, processing speed, and fluid intelligence. All continuous predictor variables were centered prior to modeling in order to improve the interpretation of our model estimates.

Results

Simon task data were unable to be collected from one participant due to technical issues encountered during online task administration (n = 41). Additionally, due to low accuracy rates (< 50%), ANT data from three participants were removed prior to analysis (n = 39). Careful investigation of Simon data from these four participants identified no evidence against inclusion in analysis. One academic performance score was Winsorized to a value 2.5 below the group average in order to reduce the effects of extreme values. Finally, with the above exception, accuracy on both tasks was high across all participants and trial types (> 94%). For this reason, accuracy data were not analyzed and will not be discussed further.

Descriptive and correlational results are summarized in Table 1. To examine the relationship between inhibitory control, attentional control, and academic performance, we conducted linear regression. Our first model tested whether

Table 1: Descriptive statistics and correlations for study variables

	n	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13
Background information																
1. Age (years)	42	16.21	1.60	—												
2. SES (1-4 points)	42	2.42	0.70	-.39*	—											
3. English proficiency (0-1 point)	42	0.72	0.12	-.07	-.14	—										
Fluid intelligence																
4. CAT4 non-verbal (50-160 points)	42	120.71	12.89	.10	.08	-.10	—									
Academic performance																
5. GPA (0-4 points)	42	3.88	0.14	-.42**	.27	.02	-.18	—								
Processing speed																
6. Simon neutral trial	41	471	47	-.06	-.06	-.01	-.10	-.12	—							
7. Flanker neutral trial	39	498	47	-.05	-.01	.04	.13	.16	.39*	—						
Inhibitory control																
8. Simon IC$^{\text{I-C}}$	41	30	45	.12	.00	.07	.21	-.24	.08	-.13	—					
9. Simon IC$^{\text{I-N}}$	41	11	29	.08	.10	-.03	.22	-.04	-.08	.10	.42**	—				
10. Flanker IC$^{\text{I-C}}$	39	36	34	.05	-.01	.15	-.14	.01	-.18	.09	-.21	-.22	—			
11. Flanker IC$^{\text{I-N}}$	39	34	39	.16	.02	.06	.04	-.40*	-.14	-.19	-.03	.04	.37*	—		
Attentional function																
12. Alerting effect (No Cue-Double)	39	52	22	.03	-.04	.08	.13	.01	.13	.46**	-.15	.02	-.02	.01	—	
13. Alerting effect (No Cue-Center)	39	45	23	.10	-.19	.26	.02	-.07	.08	.25	-.22	-.05	-.04	.14	.80***	—
14. Orienting effect (Center-Spatial)	39	22	28	.16	-.18	-.16	.03	.03	.12	.32*	.17	.15	-.11	-.21	.11	-.12

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

differences in inhibitory control or attentional control alone could predict academic performance. Models for Simon task inhibitory control were not significant, regardless of whether the IC$^{\text{I-C}}$, F (1, 39) = 2.428, p = .127, or IC$^{\text{I-N}}$ index was used as a predictor, F (1, 39) = 0.064 p = .802. Both models explained 2% or less of the variance in academic performance. The regression model for flanker IC$^{\text{I-C}}$ was not significant, F (1, 37) = 0.004, p = .948, explaining less than 0.1% of the variance in academic performance. The alternative model containing flanker IC$^{\text{I-N}}$ as a predictor was significant, F (1, 37) = 8.647, p = .006, and explained 19% of the variance in academic performance.

Models for alerting network efficiency were not significant, regardless of whether the index was calculated as the difference between no cue and double cue trials, F (1, 37) = 0.187, p = .668, or no cue and center cue trials, F (1, 37) = 0.685, p = .413, explaining less than 1% and 2% of the variance in academic performance, respectively. Finally, the regression model for orienting network efficiency was not significant, F (1, 37) = 0.011, p = .915, explaining less than 0.1% of the variance in academic performance. Based on these results, the decision was made to only include flanker IC$^{\text{I-N}}$ as a predictor in additional models.

The regression model containing gender, age, SES, English language proficiency, processing speed, and fluid intelligence on the first step was significant, F (6, 32) = 3.139, p = .016, explaining 37% of the variance in academic performance. Flanker IC$^{\text{I-N}}$ added on the second step explained an additional 10% of the variance in academic performance, F (7, 31) = 4.018, p = .003, resulting in a significantly improved model ΔF (1, 31) = 6.218, p = .018. This finding supports that inhibitory control can account for unique variance in academic performance beyond gender, age, SES, English language proficiency, processing speed, and fluid intelligence. Estimates for our final model are reported in Table 2.

Discussion

Our findings show that one index of inhibitory control, calculated as the difference in average RT between incongruent and neutral trials on the flanker task, accounts for a significant amount of unique variance in academic performance. This finding was identified in a sample recruited from an understudied population of Chinese adolescents enrolled in an English-immersive high school program in China. These results contribute to our understanding of how differences in cognitive abilities can underlie differences in academic performance, and can help inform practices in student assessment and placement in support of matching students with the most appropriate program of study to maximize their academic development.

Dissociable dimensions of executive function, including inhibitory control, play a crucial role in academic and life success (Diamond, 2013). Students with improved inhibitory control are likely better able to focus on tasks both within and outside of the classroom, ignoring the ever-growing number of distractions present in their environments. This improved focus may result in superior academic performance, a prediction supported by evidence of poor academic performance in students with ADHD, a disorder partially characterized by impaired inhibitory control (Daley & Birchwood, 2010; but see Hupfeld et al., 2019). The supported relationship between these variables has fueled interest in the development of interventions aimed at developing inhibitory control in students (e.g., Wilkinson et al., 2020), with the aim of improving educational outcomes. Our findings further highlight inhibitory control as a key dimension for future research focus in this area of inquiry.

Table 2: Linear regression predicting academic performance (n = 39)

Effect	Estimate	*SE*	95% CI	*p*
Intercept	3.863	0.021	3.82 - 3.91	< .001
Gender	-0.057	0.042	-0.14 - 0.03	.190
Age	-0.037	0.013	-0.06 - -0.01	.008
SES	0.038	0.028	-0.02 - 0.1	.182
English proficiency	0.007	0.149	-0.3 - 0.31	.963
CAT4 non-verbal	0.0001	0.001	-0.003 - 0.003	.933
Flanker neutral trial	0.0001	0.0004	0.0007 - 0.001	.726
Flanker $IC^{I\text{-}N}$	-0.001	0.0005	-0.002 - -0.0002	.018

Note. Intercept represents grand mean. Female set as reference level

Over the last decade, investigation of the cognitive factors underlying observed differences in academic performance has shifted focus to executive function (Cortés Pascual et al., 2019). This body of work has identified a range of mixed, sometimes developmentally or culturally-specific patterns between these variables. One robust finding has been the significant predictive power of working memory, a component of updating, starting towards the end of middle childhood. Our findings conflict with the observation that, around the same age, inhibition loses its predictive power (e.g., Senn et al., 2004). This may result due to differences in how inhibitory control has been operationalized, as our findings support that different indices are not necessarily equivalent. While the present study did not include a measure of working memory, evidence of negligible relationships between this dimension and inhibitory control measures on flanker and Simon task performance support that our findings cannot otherwise be explained by differences in working memory (e.g., Wilhelm et al., 2013).

We report that a single index of inhibitory control, not fluid intelligence or attentional control, explained a significant amount of unique variance in academic performance. While both the Simon and flanker tasks are thought to measure the same dimension of executive function, these tasks differ in the nature of conflict they present (Kornblum, 1994). Interestingly, only the index computed as the difference between incongruent and neutral trials on the flanker task was significantly related to academic performance. Recently, the observation that congruent trials enhance performance has fueled the argument that the calculation of inhibitory control as the difference between incongruent and congruent trials is flawed (Schroeder et al., 2016). The absence of a significant association with attentional control could have resulted from our focus on altering and orienting, processes that might be less crucial in academic performance. Our findings support the conclusion that a “purer” measure of inhibitory control derived from a stimulus-stimulus conflict task is a significant predictor of academic performance.

Findings from the present study must be considered in light of a few limitations. The absence of a working memory measure is a clear weakness in our study, but perhaps not as large a concern for reasons described above. Secondly, our measure of academic performance was limited to school-reported overall GPA. While this is a common way that academic performance is operationalized, these grades may have limited external validity. Additionally, given the characteristics of our sample, it is possible our findings reflect a culturally-specific relationship between inhibitory control and academic performance (e.g., Lan et al., 2011; Thorell et al., 2013). Finally, our sample was not balanced by gender due to convenience sampling.

In summary, we identified that individual differences in inhibitory control can predict academic performance in Chinese high school students. The predictive power of inhibitory control was still significant even when including gender, age, SES, English proficiency, fluid intelligence, and processing speed in our model. Further research is needed in order to better characterize the features and explore the directionality of this observed relationship.

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