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Research article

Executive functions as mediators between socioeconomic status and academic performance in Chinese school-aged children☆

Kean Poon [a,b,*], Mimi S.H. Ho [b], Kee-Lee Chou [c]

[a] School of Education, University of New South Wales, Sydney, Australia
[b] Department of Special Education and Counselling, The Education University of Hong Kong, Hong Kong
[c] Department of Asian and Policy Studies, The Education University of Hong Kong, Hong Kong

HIGHLIGHTS

- This study examined (1) the mediating effects of executive function in the association between socioeconomic status and academic performance; and (2) the differences in executive function and academic performance in three core subjects between Chinese children who are below and above the poverty line.
- Both socioeconomic status groups exhibited differences in cognitive flexibility, working memory, and academic performance in all three core subjects.
- The socioeconomic status-achievement relationship was mediated by cognitive flexibility and working memory but not inhibition. Working memory was a stronger mediator than cognitive flexibility in explaining academic performance.

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ABSTRACT

Background: It is well-documented that socioeconomic status (SES) and academic performance in school-aged children are closely related. However, little is known about how the three core executive functions (EFs), inhibition, working memory, and cognitive flexibility, mediate the association between the two. Moreover, most previous studies examined SES disparities in Western countries, how such disparities in EF and academic performance manifest in the Chinese context, where a distinctive EF profile and learning experience are observed, remains uncertain. The current study explored: (1) the mediating effects of the three core EFs in the association between SES and academic performance; and (2) the differences in EF and academic performance in three core subjects between Chinese children who are below and above the poverty line.

Methods: Of the 385 students sampled, 205 are in the low-SES group and 180 are in the middle-high SES group.

Results: A structural equation model showed that the SES-academic performance relationship was fully mediated by cognitive flexibility and working memory but not inhibition. Working memory was a much stronger mediator than cognitive flexibility, suggesting that working memory may correlate with childhood SES and academic performance in Chinese children. An analysis of covariance suggested that compared to the middle-high SES group, the low-SES group demonstrated poorer working memory and academic performance in all three subjects after controlling for age and IQ. Interestingly, children with low-SES were found to have better cognitive flexibility than children with middle-high SES.

Conclusions: These findings suggest that interventions targeting working memory may be an important area to improve children's academic performance.

1. Introduction

There is a gap between the educational achievement of disadvantaged and advantaged children, which exacerbates intergenerational poverty. Child poverty negatively impacts academic outcomes and poses an economic cost to society (Haft and Hoeft, 2017). Hence, understanding how socioeconomic adversity generates early academic risk is crucial. One pathway to explaining how socioeconomic status (SES) relates to academic performance is through its effect on cognitive development. Out of all the cognitive deficits, SES is considered the dominant predictor of executive function (EF) (Noble et al., 2007), predicting academic performance (Lawson and Farah, 2017).

☆ This study was approved by the Human Research Ethics Committee of The Education University of Hong Kong.

* Corresponding author.
E-mail address: keanpoon@gmail.com (K. Poon).

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While a substantial amount of research has been undertaken into the impact of SES on cognitive outcomes in Western countries, research remains sparse in the Chinese context, where there is a strong focus on academic success, and formal education in inhibitory and attention control begins at age three (Gandolfi et al., 2014). In this academic-oriented culture with its unique classroom experience, one may expect a distinctive SES-achievement gap in terms of EF and academic performance. The current study explores the mediating effects of EF in the association between SES and academic performance, and the differences in EF and academic performance between Chinese children who are below and above the poverty line.

1.1. The mediating role of executive function between socioeconomic status and academic performance

There is growing research interest in the mechanism by which SES affects academic performance via cognition (e.g., Waters et al., 2021), as malleability in training and early intervention has been indicated as significant (Hsu et al., 2014; Zhang et al., 2018). Research into this SES-achievement gap targets EF, which both predicts academic achievement (e.g., Best et al., 2011) and correlates with SES (Micalizzi et al., 2019). EF controls thoughts and decision-making toward goals or objectives (Zelazo and Carlson, 2012), and can be subdivided into inhibition, cognitive flexibility (or shifting), and working memory (Miyake et al., 2000; Scott, 1962). Cognitive flexibility is the individual's capacity to switch from one task to another or think about multiple concepts simultaneously; inhibition suppresses powerful but unwanted behavior allowing the mind to focus on relevant information; and working memory refers to the brain's ability to process and store information for performing daily activities (Miyake et al., 2000). These EF skills are also known as cool EFs as they involve abilities that are not emotionally dependent (Zelazo and Carlson, 2012).

Interestingly, researchers believe that SES relates to the three domains of EF in different ways (e.g., Kelkar et al., 2013). Across multiple studies, low-SES children are shown to generally perform worse on working memory and inhibition tests (Noble et al., 2007), however no relationship is shown between SES and cognitive flexibility. The findings for SES disparities in cognitive flexibility are mixed. While SES-related disparities in cognitive flexibility are observed in some studies (Ursache et al., 2016), others reported that cognitive inflexibility is not more apparent in poor children (Pollak et al., 2010), and in some instances, children who grow up in adverse environments perform cognitive flexibility tasks better than those who do not (Mittal et al., 2015). Thus, it remains unclear how SES affects the individual EF components and, more importantly, how the SES disparity of individual EF components impacts academic learning.

Despite years of research confirming the direction, strength, and type of links among SES, EF, and academic performance (Lee et al., 2013), the role of EF in mediating between SES and academic performance is underexplored (Chung et al., 2016). There are two studies which detected partial or full mediation effects of EF between SES and various academic measures (Micalizzi et al., 2019; Rosen et al., 2019). Rosen et al. (2019) examined income and academic performance as a single construct via working memory using path analysis. Micalizzi et al. (2019) used cognitive flexibility and inhibitory control as mediating variables to examine how SES impacts school readiness. Although these two studies show the mediating influence of EF in SES and academic performance, neither includes the three measures of working memory, inhibition, and cognitive flexibility, nor do they study their distinct contributions to core academic subjects. Considering that the three EF domains differ in the way SES affects them, and each domain has distinct implications for various academic skills, it is important to explore whether distinct executive processes uniquely mediate the SES-academic performance gap.

1.2. Cultural differences in executive function and learning experience

The EF of Chinese and North American children have been found to differ significantly in previous research (e.g., Oh and Lewis, 2008), whether such a discrepancy affects the SES-academic gap is an interesting topic. Sabbagh et al. (2006) compared the performances of 109 Chinese children and 107 American children on EF tasks (e.g., Stroop, card sorting, and tower building), and showed that Chinese students outperformed their American counterparts on most EF tasks. Another cultural study on EF was also reported by Kelkar et al. (2013), with Western participants demonstrating significantly higher switching competency and accuracy, and Eastern participants significantly faster on inhibition subtests. Both groups were found to have similar levels of working memory.

Subsequent research suggested that differences in learning experiences appear to account for disparities in EF (Kelkar et al., 2013; Last et al., 2018). For instance, Chinese children often receive intensive training in inhibitory and attention control in their early classroom experience. Lan et al. (2009) noted that Chinese teachers often give their students more explicit instructions to self-regulate, such as “sit properly when listening” and “do not talk in class”. Their proactive instructions heavily stress attention control, which fosters early inhibition development. On the other hand, Western culture emphasizes analytical thinking strategies and reasoning skills which may reinforce advanced switching ability (Chiao et al., 2009).

Chinese culture emphasizes academic excellence. Formal schooling in Hong Kong (HK) requires children to begin reading in English and Chinese and learn Mathematics at the age of three. As a result of this early exposure to formal education and most families are willing to invest in private tutoring (Eng, 2019), there is likely to be a growing gap in academic performance of children below and above the poverty line.

Although previous research found that children from high-SES backgrounds performed significantly better than children from low-SES backgrounds in academic performance in the United Kingdom (von Stumm et al., 2020), United States (Destin et al., 2019; Lurie et al., 2021), Turkey (Nedim Özdemira et al., 2014), Australia (Thomson et al., 2017), and China (Li et al., 2020), most examined the SES-academic disparity as a general domain. Findings on how the disparity applies to various subjects remain limited and mixed. A recent study conducted by Lurie et al. (2021) reported that SES was positively associated with language scores in children in the United States. Study from Australia suggested that students from high-SES backgrounds performed significantly higher than students from low-SES backgrounds across all subjects (Thomson et al., 2017). Considering the well-known socioeconomic gradient in academic performance, understanding how SES affects various academic subjects in the Chinese context would provide unique insight into culturally sensitive early intervention.

1.3. Aims of the current study

Despite research consistently showing the links between academic performance and socioeconomically disadvantaged children, several research gaps remain. Firstly, the majority of empirical studies focus on understanding or verifying the association between SES and academic performance. Research focusing on the mechanisms by which SES impacts academic performance through the three core elements of EF is limited. Without addressing the three core elements, it remains unclear whether the existing measures of EF provide a full explanation of the associations between SES and academic performance. Secondly, given that previous studies have shown substantial differences in EF between Asian and Western children, the Chinese sample offers valuable information for designing culturally sensitive interventions. Finally, most previous studies examined SES disparities in academic performance as a general domain; how such disparities apply to different subjects remains uncertain. This study aimed to examine (1) the mediating effects of the three core EFs in the association between SES and academic performance; and (2) the differences in EF and the three core subjects between Chinese children who are below and above the poverty line. The findings of this study are hoped to have an impact on developing better interventions and educational programs.

2. Materials and methods

2.1. Participants

All public primary schools in HK were invited by mass invitations, and the schools to be investigated were selected at random so the proportion of students correspond to the number of students within that area. Following this process, four schools from HK Island ($n = 1$), Kowloon Peninsula ($n = 1$), and the New Territories ($n = 2$) were selected. Four hundred and three students from four primary schools ($M_{age} = 8.0 \pm 1.0$ years) who met the following criteria participated: (1) aged 7–9 years, (2) in grade 1 to 3, (3) native speaker of Cantonese and first written language is Chinese, (4) low or middle-high SES status, and (5) normal intelligence (scored ≥80 on the Raven's Standard Progressive Matrices). This standard intelligence quotient (IQ) score was recommended as the cutoff point for language acquisition (Rice, 2016). There were 214 boys (53.1%; $M_{age} = 8.0 \pm 1.0$ years) and 189 girls (46.9%; $M_{age} = 7.9 \pm 0.9$ years).

2.2. Procedures

This study was approved for ethical purposes by the authors' institution. Participants were invited through local primary schools to take part in a screening procedure, including an intelligence test. Students who met all criteria were then invited to take part in the EF assessments with their assent and written consent from their parents. Research assistants were trained to administer all EF assessments to participants individually in a quiet classroom setting. Demographic information was collected via a family survey, and students' academic scoring was provided by teachers.

2.3. Instruments

2.3.1. Socioeconomic status

A questionnaire was used to collect demographic data from parents including educational attainment and monthly household income levels. A 4-point scale was used to quantify the parents' education level ranging from 1 (*primary school or below*) to 4 (*master's degree or above*).

2.3.2. Intellectual ability

A measure of general intellectual ability was assessed using The Raven's Progressive Matrices (Raven et al., 2000). The shortened version of Standard Progressive Matrices (SPM; Raven et al., 1998) was selected for this study. The SPM is a widely used nonverbal test of deductive ability and consists of visual problems. Each item contains a figure with a missing part; participants need to observe the visual pattern of the figure and choose the correct answer to fit the missing element out of multiple choices. The SPM consists of 60 items, with 12 items in each set (A–E). The reliability of the SPM was .88 in children (Raven et al., 1998).

2.3.3. Inhibition

The non-computerized Stroop Color and Word Test (Stroop, 1935) was utilized to test inhibition (e.g., Ellis et al., 2009). Three separate 1-minute rounds were conducted under each condition: word, color, and color-word conditions. Participants were required to read as much printed text aloud as possible. The first two rounds (naming only by word or color) gauges naming speed while the last round measures participants' ability to control the dominant, automatic choices (i.e., read out the color instead of reading the color of the ink used; Ellis et al., 2009). The Hong Kong Psychological Society (2022) has validated the Stroop Color and Word Test in Chinese.

2.3.4. Cognitive flexibility

Cognitive flexibility was measured with The Attention Switching Test (Cambridge Neuropsychological Test Automated Battery; CANTAB, 2022). Every trial begins with a computer screen displays either a left or right arrow. Participants clicked on a left or right arrow button as quickly as they could on the screen to indicate which way the arrow was pointing. Cognitive flexibility was measured by switching cost—the disparity in reaction time between congruent trials (the same instruction for two consecutive trials) and incongruent trials (instruction different from the previous trial). Higher switching cost represented a weaker ability in cognitive flexibility (Rubinstein et al., 2001).

2.3.5. Verbal working memory

Using the third version of the Wechsler Intelligence Scale for Children (Wechsler, 1981), backward digit spans subtest was administered to assess verbal working memory. Participants were asked to repeat numbers read out loud, from two to nine digits, in reverse order. Successful participants will retain auditory information and discern relevant from irrelevant information. This subtest has been frequently used to measure verbal working memory (e.g., Jacobson et al., 2011). Scores were calculated using an age-standardized scale.

2.3.6. Visual-spatial working memory

A computerized Spatial Working Memory Test was selected from CANTAB (2022) to measure visual-spatial working memory. Participants are shown several boxes on screen, and they have to find a yellow-colored token hidden in one of them. Only one token can be found per search. After collecting the token, they must find another one until they have found them all (the number of tokens equals the number of boxes). Once a yellow-colored token has been found, it will never appear in that box again. The number of boxes increases with the difficulty level, from four to a maximum of eight. The "between error" indicates the number of times participants searched for a box where a token had previously been found. An increased number of between errors reveals inferior visual-spatial working memory (CANTAB, 2022).

2.3.7. Academic performance

Student's academic performance was reported by their teachers based on the recent school results from 1 (Bottom 20%) to 2 (21%–40%), 3 (41–60%), 4 (61–80%) and 5 (Top 20%; Lee and Bowen, 2006). The academic performance of three core subjects in HK were Chinese, English, and Mathematics.

3. Data analysis

To achieve the aims of this study, numerous statistical methods were introduced. For the first aim, a structural equation modelling (SEM) was analyzed the mediating effects of EF in SES-academic performance relationship using AMOS (AMOS 26.0; Arbuckle, 2019). As recommended by Byrne (2010), the maximum likelihood estimation method was preferred owing to the Mardia's (1970) coefficient of multivariate kurtosis being greater than 1.96 (normalized estimate = 2.54). A good fitting model, based on Hu and Bentler (1999), is one in which the Comparative Fit Index (CFI) value is ≥.90 and the Standardized Root Mean Square Residual (SRMR) and the Root Mean Square Error of Approximation (RMSEA) along with its 90% CI values are ≤.08.

For the second aim, EF (cognitive flexibility, working memory, inhibition) and academic performance in English, Chinese, and Mathematics between low-SES and middle-high SES group were analyzed and compared by an independent analysis of covariance (ANCOVA) for intergroup differences. It can be used to control for one or more covariates (i.e., age and IQ) in the SPSS statistical software package (version 26.0; IBM Corp, 2019). Bivariate correlations were used to identify what relationships the variables have and the strengths of any associations.

In addition to the research aims, the comparisons of the demographic variables (i.e., age, income-to-needs ratio (INR), parents' education level) among the two groups were analyzed by an independent samples *t*-test for intragroup differences. A chi-square test was also conducted using gender distribution in the two SES groups.

4. Results

4.1. Data screening

The variation in family income was large in our sample; Winsorization was used to detect univariate outliers (Tukey, 1962). Values that exceeded 3 *SDs* were identified as outliers, and the original values were replaced by the nearest value of an observation not seriously suspected (Tukey, 1962). After cleaning up outliers ($n = 18$), the final sample size yielded 385 respondents ($M_{age} = 8.0 \pm 1.0$ years).

4.2. Results of socioeconomic status analysis

The HK government's INR was used to divide the sample into two basic groups. Family's INR is based on dividing household income by the poverty threshold relative to the number of family members. The INR is defined as an indicator of financial capital as well as paternal and maternal education level. The official poverty threshold was then determined by the Census and Statistics Department, the Government of the Hong Kong Special Administrative Region (2022). Families with an INR between 0 and 1 were classified as living below the poverty line (low-SES) and those with an INR greater than one were classified as living above the poverty line (middle-high SES; Noble et al., 2006). In a factor analysis using maximum likelihood extraction, maternal education, paternal education, and income-to-needs were combined into one composite score for each individual. A single factor accounted for sixty-six percent of the variance across the three variables. Accordingly, each participant's SES composite score was determined by factor loading. This method has been used in previous research on the effects of SES (Chen et al., 2018; Chung et al., 2016), which was deemed appropriate for this study. The sample consisted of 205 participants with low-SES ($M_{age} = 8.2 \pm 1.0$ years) and 180 participants with middle-high SES ($M_{age} = 7.7 \pm 0.9$ years).

4.3. Group differences in demographic variables

Our results showed significant group differences in age (t (383) = 4.52, $p < .001$], IQ (t (382) = 2.09, $p < .05$), INR (t (240) = 13.19, $p < .001$), paternal educational level (t (343) = 4.13, $p < .001$), and maternal education level (t (340) = 4.70, $p < .001$). Specifically, students in the middle-high group SES had higher IQ score, INR, paternal educational level, and maternal education level than students in the low-SES group. No significant gender difference was observed, χ^2 (1, 385) = 1.40, p = .24. The percentages of males from a low-SES background and from a middle-high SES background were 56% and 44%, respectively. Females from low and middle-high SES backgrounds each accounted for 50%. As age and IQ significantly differed between the two groups, these two variables served as controlling variables in additional analysis (see Table 1).

Table 1. Descriptive statistics in the demographic variables between low-SES and middle-high SES groups.

Variable	Low-SES ($n = 205$)		Middle-high SES ($n = 180$)		t
	M	*SD*	*M*	*SD*	
Age	8.17	.99	7.73	.92	4.52***
Intelligence quotient	109.28	15.24	112.27	12.77	2.09*
Income-to-need ratio	1.19	.57	2.56	1.28	13.19***
Paternal education level	2.30	.57	2.57	.71	4.13***
Maternal education level	2.26	.48	2.52	.61	4.70***

*$p < .05$. ***$p < .001$.

4.4. Correlations between the study variables

Significant correlations were found between SES and academic subjects, cognitive flexibility, verbal working memory, and parents' education level. Cognitive flexibility, verbal working memory, and visual-spatial working memory were also significantly correlated with academic subjects. Only the correlations between inhibition and academic subjects were non-significant ($p > .05$) (see Table 2).

4.5. Mediational effects

The mediational effects in the hypothesized model were examined following the recommendation by Holmbeck (2002). Initially, a model estimating the direct path from the independent variable to the outcome variable was tested. The model hypothesizing the path from SES to academic performance provided a good fit to the data: $\chi^2/df_{(4)} = 7.30$; CFI = .97; SRMR = .03; RMSEA = .08. After controlling for age and IQ, the significant path from SES to academic performance was found (β = .23, $p < .001$).

In the second step, a partial mediation model was evaluated using both direct and indirect pathways from SES to academic performance via inhibition, cognitive flexibility, and working memory. The model was good: $\chi^2/df_{(19)} = 3.78$; CFI = .95; SRMR = .05; RMSEA = .08. There were significant paths between SES and cognitive flexibility (β = .14, $p < .01$), cognitive flexibility and academic performance (β = .26, $p < .001$), SES and working memory (β = .36, $p < .01$), as well as working memory and academic performance (β = .52, $p < .01$) after controlling for age and IQ. SES and academic performance (β = .09, $p > .05$), SES and inhibition (β = .06 $p > .05$), as well as inhibition and academic performance (β = -.05, $p > .05$) did not show any significant path coefficients (Figure 1).

A full mediation model was examined in the final step, where the direct path between SES and academic performance was restricted to zero (model fit = $\chi^2/df_{(20)} = 3.62$; CFI = .95; SRMR = .05; RMSEA = .08). The chi-square (χ^2) difference test was used to compare partial and full mediation models, and the change in χ^2 statistic was non-significant ($\Delta df_{(1)} = .16$). The Akaike information criterion (AIC) was also used to compare the models, where a smaller value is preferred (Kline, 2005). The full mediation model (AIC = 140.45) was more parsimonious than the partial model (AIC = 141.86). Taken together, the full mediation model was retained.

4.6. Indirect effects and total effects

The indirect effects of SES on academic performance via cognitive flexibility (standardized indirect effect = .08, $p < .01$, 95% BC CIs = .03–.14) and working memory (standardized indirect effect = .41, $p < .01$, 95% BC CIs = .22–.60) were significant in using the bootstrapping method (i.e., 95% bias-corrected confidence intervals [BC CIs] with 1,000 bootstrap resamples; Efron, 1988; see Table 3). Based on the recommended values (.01 = small, .09 = medium, and .25 = large effect sizes; Preacher and Kelley, 2011), small, medium, and large effects were generated by the strength of the association between variables. In the final model, inhibition explained 1% of the variance, cognitive flexibility contributed 5% of the variance, working memory contributed 34% of the variance, and academic performance explained 30% of the variance (Figure 1). The direct and indirect impacts of SES on academic performance is the total effect (Byrne, 2010). In this present study, SES has a total effect of .22 on academic performance.

4.7. Group differences in executive function and academic performance

Regarding the outcome variables, ANCOVA showed significant differences in cognitive flexibility (F (1, 381) = 5.92, $p < .05$), verbal working memory (F (1, 381) = 7.44, $p < .01$), visual-spatial working memory (F (1, 381) = 6.70, $p < .05$), Chinese (F (1, 381) = 10.77, $p < .01$), English (F (1, 381) = 26.24, $p < .001$), and Mathematics (F (1, 381) = 5.64, $p < .05$) between the two groups. Only inhibition (F (1, 381) =

Table 2. Correlations coefficients between all study variables in Chinese school-aged children ($N = 385$).

Variable	Task	1	2	3	4	5	6	7	8	9	10
1. SES composite score		–									
2. Paternal education		.17**	–								
3. Maternal education		.21***	.62***	–							
Executive Function											
4. Inhibition	Stroop Color and Word Test	.05	.04	.05	–						
5. Cognitive flexibility	Attention Switching Test	.12*	.15**	.14**	.08	–					
6. Verbal working memory	Backward Digit Spans Subtest	.14**	.06	.16**	.04	.23***	–				
7. Visual-spatial working memory	Spatial Working Memory Test	−.04	.02	.03	−.09	.22***	.13**	–			
Academic performance											
8. Chinese		.17**	.13*	.06	−.02	.28***	.18***	.15**	–		
9. English		.25***	.16**	.12*	−.01	.27***	.19***	.18***	.79***	–	
10. Mathematics		.12*	.10	.07	.01	.32***	.15**	.20***	.77***	.77***	–

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

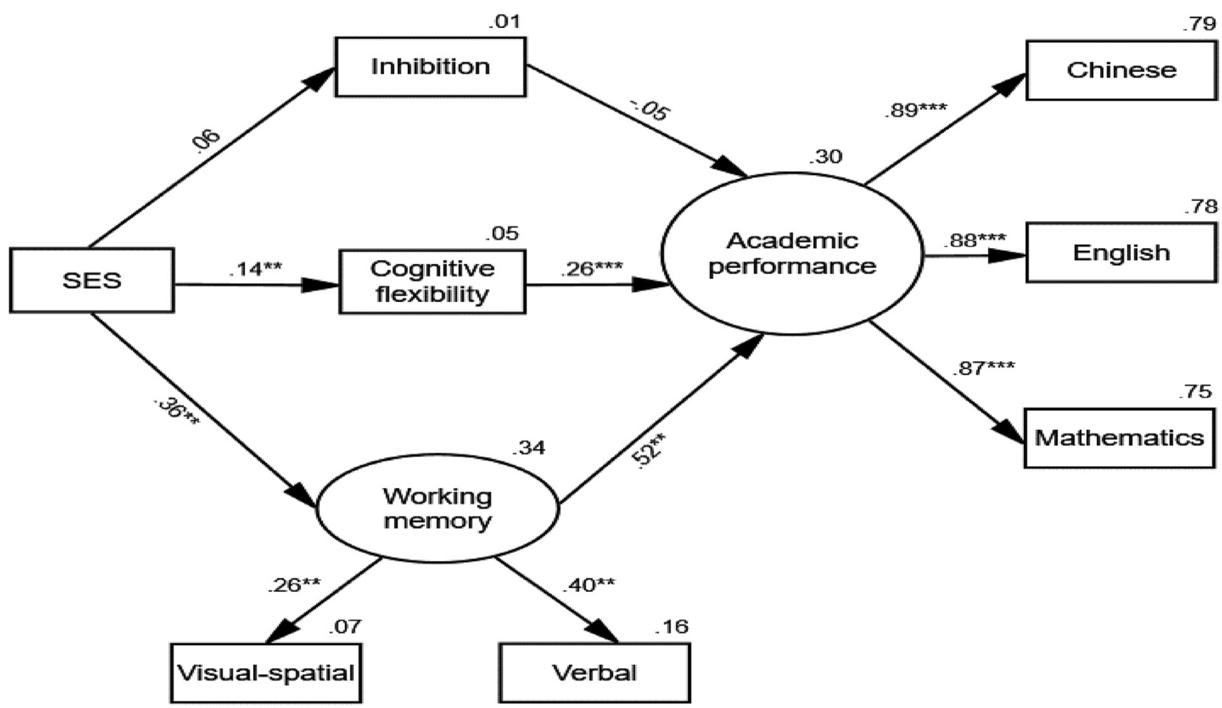

Figure 1. The mediating effect of executive function in the association between socioeconomic status and academic performance. *Note.* Age and IQ were used as covariates to control for SES, inhibition, cognitive flexibility, working memory, and academic performance. These covariates were omitted for ease of viewing. **$p < .01$. ***$p < .001$.

1.00, $p > .05$) was non-significant between the two groups even controlled for age and IQ (see Table 4).

5. Discussion

The overarching aim of this study was to explore the mediating effects of the three core EFs in the association between SES and academic performance, and to understand the differences in EFs and academic performance between Chinese children who are below and above the poverty line.

5.1. *The mediation effects of executive function*

Our mediation model revealed an indirect relationship between SES and academic performance through cognitive flexibility and working memory. These findings are in accordance with previous research which shows that working memory and cognitive flexibility mediated the association between household income and academic performance (e.g., Rosen et al., 2019). In our findings, the SEM model accounted for 1% of the variance in inhibition and 5% of the variance in cognitive flexibility, indicating a small effect, while the 34% variance in working memory constitutes a large effect (see Figure 1). Although both working memory and cognitive flexibility are significant mediators, working memory was a much stronger mediator of academic performance than cognitive flexibility. In fact, working memory plays an essential role in many cognitive functions, such as planning, organization, attention, decision-making, and strategizing (Dehn, 2008; Gathercole et al., 2003). McGrew and Woodcock (2001) stated that working memory plays a unique role in academic performance, even when IQ is controlled for. A longitudinal study carried out by Alloway and Alloway (2010) even suggested that children's early performance in working memory is a better predictor of later academic performance than IQ. Evidently,

Table 3. SES and academic performance: indirect effects via cognitive flexibility and working memory.

Indirect effect	Outcome variable	Point estimate	95% BC CI
SES → cognitive flexibility	Academic performance	.08**	.03–.04
SES → working memory	Academic performance	.41**	.22–.60

** $p < .01$.

working memory should be a key target for interventions aimed at reducing the impact of SES on academic performance (Gathercole et al., 2006).

Based on the correlational analysis, verbal working memory was shown to be better correlated with language subjects, while visual-spatial working memory was associated with Mathematics. These findings, alongside those of other studies, suggest that different types of academic success utilize verbal and visual-spatial working memory to varying degrees (Baddeley, 1986, 2000). A meta-analysis showed that language subjects correspond with verbal working memory even after controlling for IQ, verbal reasoning, naming speed, and other cognitive abilities (Daneman and Merikle, 1996; Swanson and Jerman, 2007). Mathematics, in contrast, tends to rely more heavily on visual-spatial working memory than verbal working memory (McKenzie et al., 2003). Therefore, it is possible that the verbal and visual-spatial working memory capacities of low-SES children are associated with the learning and mastery of tasks related to language and Mathematics.

5.2. Disparities in intelligence quotient and executive function below and above the poverty line

Consistent with previous studies (Piccolo et al., 2016), the students with low SES performed worse in IQ tests than the students with middle-high SES. It is plausible that as comparing to students from middle-high SES families, students with low SES tend to live in more deprived areas that are less conducive to intellectual engagement (Hanscombe et al., 2012). Moreover, individual differences in cognitive ability may be further exacerbated by disparities of available resources, learning opportunities, and support, which could influence IQ scores (von Stum and Plomin, 2015).

Based on our findings, as in previous studies (e.g., Leonard et al., 2015), there were significant disparities in working memory between the two SES groups, with students below the poverty line exhibiting more working memory weakness than those above. Specifically, we measured both verbal and visual-spatial working memory to understand how poverty affects different area of working memory. In contrast to previous studies which reported asymmetrical working memory deficits in low-income children (Tine, 2014), our study showed symmetrical deficits in visual and verbal working memory among low-income children. Nonetheless, it is possible that the low-SES group consists of a larger proportion of new immigrants from China than the average-SES group (Society for Community Organization, 2022). This might be relevant, since new immigrants are more likely to perform worse on verbal working memory tasks than they would if the tasks were given to them in their mother language (e.g., Mandarin). It is, therefore, likely that the average verbal working memory score of the low-SES group underestimates their real abilities.

In general, differences in the developmental contexts within SES groups could influence children's cognitive development, especially working memory, as chronic stress is known to negatively affect working memory (Evans and Schamberg, 2009). In fact, cognitive load mediates the association between SES and working memory, an indicator of mental workload, which is equivalent to the mental resources simultaneously elicited during the execution of a task (Sweller, 2010). Chronic stressors include an impoverished living environment, poor schooling (Nampijja et al., 2018), and family instability (Gaydosh and Harris, 2018). The longer children live in poverty, the more stress they experience; and, eventually, the more harm is done to their working memory capacity (Evans and Schamberg, 2009). This explanation is supported by a meta-analysis and comprehensive review showing that stress can induce psychological exhaustion, leading to cognitive impairment, including impairment of working memory (Shields et al., 2017).

Concerning cognitive flexibility, children with low-SES were found to have lower switching cost than their affluent peers, indicating that children in the low-SES group demonstrated better cognitive flexibility than children in the middle-high SES group. However, findings concerning the relationship between cognitive flexibility and SES are mixed (Ursache et al., 2016). For example, Ursache et al. (2016) discovered that children from high-income families had better cognitive flexibility than children from low-income families. Clearfield and Niman (2012) investigated the longitudinal development of cognitive flexibility in low-SES infants and reported delayed responses at 6, 9, and 12 months. Blair et al. (2005), in contrast, argued that stress reactivity (represented by changes in cortisol levels) is linked with cognitive flexibility in children who grow up in stressful environments. Similar results were reported by Mittal et al. (2015), showing that individuals who grow up in environments that are more challenging and unpredictable demonstrate greater cognitive flexibility than those who grow up in typical environments (Mittal et al., 2015). It is therefore possible that negative childhood environments can interfere with cognitive development and prevent individuals from fully developing their executive abilities. Yet, over time, the adversity and unpredictability associated with poverty might prepare disadvantaged children's brains to switch attention rapidly, enabling them to maximize gain and manage the sense of threat in their uncertain environment (Glover, 2011; Nederhof and Schmidt, 2012). As such, rather than impairing cognitive functioning, the current results add support to the idea that adversity in childhood may shape cognitive development in an adaptive manner.

Table 4. Descriptive statistics in executive function and academic performance in Chinese school-aged children with low-SES and middle-high SES.

Variable	Task	Low-SES ($n = 205$)		Middle-high SES ($n = 180$)		F	Cohen's d
		M	SD	M	SD		
Executive function							
Inhibition	Stroop Color and Word Test	10.53	2.21	10.72	2.29	1.00	.10
Cognitive flexibility (ms)	Attention Switching Test	102.27	191.59	136.59	173.80	5.92*	.25
Verbal working memory	Backward Digit Spans Subtest	8.41	2.30	8.85	2.07	7.44**	.28
Visual-spatial working memory	Spatial Working Memory Test	20.16	5.42	20.57	6.27	6.70*	.27
Academic performance							
Chinese		3.13	1.23	3.47	1.21	10.77**	.34
English		2.84	1.27	3.49	1.22	26.24***	.53
Mathematics		3.24	1.25	3.52	1.14	5.64*	.24

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

The current findings echo previous research showing that children of higher and lower-SES backgrounds did not differ in inhibitory control (e.g., Wiebe et al., 2008). In fact, it is still unclear how SES affects inhibition. Although some studies confirm a strong association between family SES and inhibitory control (Evans and Kim, 2013; Lonigan et al., 2017), most did not control for measured or unmeasured covariates. For instance, Willoughby et al. (2012) reported no association after controlling for potential covariates. Other studies have also stated that poverty and adversity weaken inhibition by undermining the brain regions responsible for stress responses and self-regulation (Blair and Raver, 2016; Johnson et al., 2016). However, it could be speculated that differences in inhibition occur later in childhood, as this would comply with the view that there is a progressive development of prefrontal structures and inhibitory control in children (Best and Miller, 2010). For example, a significant discrepancy in inhibition exists between lower-SES and higher-SES children aged 10–12 years, but not those aged 6–9 (de Rosa Piccolo et al., 2016). Although the children in our sample were aged 7–9 years, future research should try to explain the true nature and effect of SES on the maturation of inhibition over time.

5.3. Disparities in academic performance below and above the poverty line

Consistent with previous findings, we revealed significant differences in performance in all three subjects (i.e., Chinese, English, and Mathematics). Like most findings, we reported marked divergence in Mathematics performance between low and middle-high SES groups (e.g., Wang et al., 2014). Children from low-SES families generally have limited mathematical skills (e.g., Klein et al., 2008) and poor number sense (i.e., magnitude, relationships, and operation of numbers; Claessens and Engel, 2013) compared to their wealthier counterparts. Mathematical knowledge can be learned through parental training in formal (e.g., counting, addition, subtraction) and informal (e.g., playing board games, card games, and shopping; Anders et al., 2012) mathematical activities. Formal mathematical activities at an early age predicted later ability to master numerical symbols and arithmetic concepts (Polk et al., 2001), whereas informal activities predicted an understanding of abstract numerical relationships that do not involve actual numerals (Ramani and Siegler, 2015).

In addition to Mathematics, the discrepancies in language subjects (i.e., Chinese and English) could be due to differing kinds of daily communication in parent–child interactions between the two groups, including daily communication and language input. Children develop a richer vocabulary and learn to understand social meaning in an environment where the parents are present every day to encourage this process (Mackey et al., 2015). Children from low-income backgrounds suffer from reduced engagement in enriching language environments (e.g., Guo and Harris, 2000) or paired reading (e.g., Serpell et al., 2005). This corresponds to past studies showing that an early parent–child communication foundation predicts later language development, demonstrating that differences in the quality of parent–child interaction among SES groups can affect literacy attainment (Hirsh-Pasek et al., 2015; Poon, 2020). Another reason for the SES discrepancies in academic subjects may due to differences in parenting and parents' education level. In this study, parents of students with middle-high SES had higher education levels than parents of students with low SES. This is commensurate with Bornstein et al.'s (2010) knowledge gap hypothesis that parents with high educational attainment and greater economic resources are likely to be exposed to, acquire, and adopt information relevant to parenting practices more rapidly than parents with less educational attainment. Given that socioeconomic factors (e.g., parents' education level, income) and parenting can shape children's educational development, future research into the relationship between SES and academic performance may extend the current study by including parenting measures (Papadakis et al., 2019). In support of this proposal, previous research found that parenting behavior mediated the relationship between SES and academic performance (Millones et al., 2014).

Although significant differences are found in all three subjects, the effect was much stronger in English ($d = .53$) than Chinese ($d = .34$) and Mathematics ($d = .24$). One possible reason for this is that HK is a bilingual metropolis, with English as one of the official languages. Parents recognize and value English proficiency as vital to success in school and career development (e.g., Jiang, 2003). Parents in HK usually have supportive attitudes towards English learning, and thus a high level of aspiration for their children's English skills (Wong, 2007). Parents from higher SES families tend to provide extra resources and assistance, and have higher expectations for, and involvement in, their children's English-language learning than the other two subjects (Valero et al., 2015).

5.4. Limitations

Although our findings are insightful, it is vital to note some limitations. Firstly, the three core elements of EF, cognitive flexibility, working memory, and inhibition, are cool EF. As suggested by Bembenutty and Karabenick (2004), hot EF, such as affective decision-making and delay gratification, play a key role in academic performance, particularly when children are expected to resist the temptation of a smaller immediate reward in preference for a bigger reward later (e.g., not watching television the night before an exam to obtain a better result). Future research should include hot EF.

A second limitation is that we only employed a cross-sectional design, which does not involve causation. For causation to be established, it is essential to adopt an experimental design to manipulate children's feelings of stress in order to determine the causal role of EF. The participants of such a study, however, could be exposed to psychological harm, which would raise ethical concerns. An alternative method would be to conduct qualitative interviews to understand the stressful experiences associated with SES. Chronic stress caused by impoverished family environments and perceived financial strain can cause temporary or permanent alternations to brain structure, particularly the prefrontal cortex, which is responsible for EF (Shonkoff and Gardner, 2012; Wilber et al., 2011).

A third limitation is the focus on just two SES domains (monthly household income and parents' education level). Future research should incorporate measurements of various aspects of SES, such as interparental conflict and household chaos, as previous research found these to affect EF (Shaver, 2007). A final limitation is that the assessment of academic performance was based on teacher reports using an interval scale. While this is easy to administer in schools, researchers may wish to consider adopting standardized achievement tests.

6. Conclusions and implications for future research

Despite these limitations, the present results provide practical guidelines for educational researchers. Firstly, our study provides key information about future interventions by suggesting that working memory and inhibition could be important mediators between SES and performance outcomes. Researchers must continue to examine the important role of EF as part of their understanding of SES effects on academic performance. Specifically, given that children with the weakest EF gain most from early EF intervention (Diamond and Lee, 2011), future studies should explore the effectiveness of early EF training, in particular in the area of working memory, on the later academic performance of disadvantaged children. Vernucci et al. (2022) implemented computer-based working memory training in typically developing children, and found that the training group significantly improved verbal working memory compared to the active control group after training and after 6-month follow-up. Future study may examine the effectiveness of EF training, especially computerized working memory training on disadvantaged children. This potentially simple and economical intervention to influence cognition, may potentially help to narrow the SES–achievement gap.

Secondly, the current study also revealed that, although significant differences are found in all three subjects, the effect was much stronger in English ($d = .53$) than Chinese ($d = .34$) and Mathematics ($d = .24$). Particularly, SES has a more significant impact on English (one of the official languages in HK) than Chinese, which is congruent with previous research that SES has a marked effect on proficiency in second language learning in non-English-speaking countries (e.g., Taiwan) (Butler and Le, 2018; Liu et al., 2020). While students from low-SES families cannot afford tutoring, providing a range of appropriate resources and supporting home literacy practices to promote children's English learning in low-SES families is essential. Using a series of take-home activities that encouraged parents to engage with their children in English learning, Tong et al. (2021) revealed that the home-based literacy activities not only contributed to students' English performance but enhance their learning motivation. This finding suggested that supporting second language learning of low-SES students maybe an important direction for academic intervention.

In conclusion, childhood poverty is not only detrimental to child development, but also has a societal economic impact in the long term. In fact, the vicious cycle of intergenerational poverty is a pressing issue worldwide. Our study provides key information about future interventions by suggesting that working memory could be an important mediator between SES and performance outcomes, and that providing a range of appropriate support to promote children's second language learning in low-SES families is essential. The findings advance the understanding of cognitive development in children and contribute to the long-term goal of developing intervention programs to improve EF in disadvantaged children, thus helping to narrow the SES–achievement gap.

Declarations

Author contribution statement

Kean Poon: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials analysis tools or data; Wrote the paper.

Mimi Ho: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Kee-Lee Chou: Conceived the experiments.

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Data availability statement

The authors do not have permission to share data.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

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