Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Executive function profiles in Chinese early adolescents: associations with academic achievement and emotional and behavioral difficulties

Hui Li
Beijing Normal University
Yiting Liang
Beijing Normal University
Jurong Xue
Dalang Experimental School
Kaiyu Gan
Beijing Normal University
Sai Ma
Beijing Normal University
Wei Liu
Beijing Normal University
Zijie Qin
Beijing Normal University
Shiyu Fang
Dalang Experimental School
Xuemin Zhang
xmzhang@bnu.edu.cn
Beijing Normal University

Article

Keywords: Executive function, latent profile analysis, sustained attention, academic achievement, emotional and behavioral difficulties

Posted Date: November 12th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11174665/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Executive function (EF) is multidimensional, yet less is known about how its components are configured within individuals during early adolescence and whether these configurations relate to academic achievement and emotional and behavioural difficulties. Using latent profile analysis, this study identified EF profiles among 489 Chinese fifth-grade students based on sustained attention, interference inhibition, response inhibition, working memory, and cognitive flexibility. Three profiles emerged: High EF, Average EF, and Attention-vulnerable EF. The High EF profile showed higher achievement in Chinese, English, and mathematics than the other profiles. Compared with the Average EF profile, the Attention-vulnerable EF profile showed lower mathematics achievement and greater hyperactivity/inattention, peer problems, and total difficulties. These findings suggest that EF heterogeneity reflects both differences in overall functioning and distinct configurations of relative strengths and weaknesses, highlighting the relevance of attention-centred vulnerabilities to individual differences in academic and behavioral functioning in early adolescence.

Introduction

Executive function (EF) refers to a set of top-down cognitive processes that support goal-directed thought and behavior and continue to develop throughout childhood and adolescence (Banich, 2009; Diamond, 2013; Miller & Cohen, 2001; Tervo-Clemmens et al., 2023). EF is important for adolescents' learning and broader functioning, with individual differences in EF consistently associated with academic achievement and emotional and behavioral difficulties (Best et al., 2011; Spiegel et al., 2021; Yang et al., 2022). Although EF comprises multiple interrelated components, most previous research has examined these components separately and focused on their average associations with developmental outcomes. Consequently, less is known about how multiple EF components are jointly configured within individuals and whether different configurations are associated with distinct patterns of academic achievement and emotional and behavioral difficulties. To address these gaps, the present study used latent profile analysis to identify EF profiles among Chinese early adolescents and examined profile differences in achievement across school subjects and in emotional and behavioral difficulties.

The Multidimensional Framework of Executive Function

EF is commonly conceptualized as a multidimensional system of control processes that are partially separable yet interdependent (Karr et al., 2018). The unity-and-diversity model identifies inhibition, shifting, and updating as three core components of EF (Miyake et al., 2000). These processes support the suppression of inappropriate responses, flexible switching between tasks or mental sets, and the monitoring and updating of information in working memory, respectively (Diamond, 2013; Miyake et al., 2000). Inhibitory control can be further distinguished between response inhibition, which involves withholding or stopping a prepotent response, and interference inhibition, which involves resolving conflict from task-irrelevant information (Friedman & Miyake, 2004; Rey-Mermet et al., 2018). These EF

processes continue to develop and become increasingly differentiated across childhood and adolescence, making early adolescence an important period for examining individual differences in their organization (Folker et al., 2025; Ma et al., 2026; Tervo-Clemmens et al., 2023).

Although sustained attention is not typically included among the three canonical EF components, the ability to maintain goal-directed attention over time is closely involved in effective executive control (Blair, 2016; Zelazo, 2015; Zelazo et al., 2016). Sustained attention refers to the capacity to maintain consistent task engagement and goal-relevant processing over prolonged periods (Robertson et al., 1997; Unsworth & Robison, 2020). Evidence further suggests that sustained attention is related to, but distinguishable from, other executive processes such as working memory and response inhibition (Deodhar & Bertenthal, 2023). Including sustained attention may therefore capture an additional dimension of individual differences in goal-directed cognitive control that is not fully represented by the canonical EF components. Accordingly, the present study examined five dimensions of executive functioning: working memory, cognitive flexibility, response inhibition, interference inhibition, and sustained attention.

The Heterogeneity of Executive Function Profiles

Although EF components are conceptually distinguishable, they covary because performance across domains reflects both shared and component-specific control processes. The unity-and-diversity framework proposes that common executive processes contribute to performance across EF components, whereas component-specific processes give rise to relative strengths and weaknesses in particular abilities (Friedman & Miyake, 2017; Miyake & Friedman, 2012). Consistent with this framework, updating, shifting, and inhibition show moderate associations while remaining distinguishable from one another (Miyake et al., 2000). Thus, individuals may differ not only in their general level of EF but also in the configuration of strengths and weaknesses across specific executive abilities.

Most research on EF structure has relied on variable-centered approaches, such as correlation and regression, to characterize average associations among EF components (Karr et al., 2018; Miyake et al., 2000). Although these approaches are informative about population-level covariation, they provide limited insight into whether distinct configurations of EF co-occur within individuals. Person-centered approaches complement this work by identifying subgroups of individuals who show similar joint patterns across multiple indicators (Bergman & Magnusson, 1997; Bergman et al., 2003). To date, relatively few studies have used person-centered methods to examine EF profiles in children and adolescents (see **Supplementary Table S1**). Across studies, solutions have ranged from two to six profiles. Broadly high, moderate, and low EF profiles have been commonly identified, alongside more uneven profiles characterized by selective strengths or weaknesses in working memory, cognitive flexibility, inhibitory control, delay of gratification, or context monitoring (Brandt et al., 2024; Carriedo et al., 2024; Chaku et al., 2022; Litkowski et al., 2020; Usai et al., 2018; Younger et al., 2024). These findings suggest that EF heterogeneity may involve both general differences in overall functioning and more differentiated patterns across specific executive abilities.

Despite these advances, two issues remain particularly relevant to the present study. First, existing studies have generally defined EF profiles using canonical executive components, with sustained attention rarely included as a distinct indicator. Because sustained attention reflects the capacity to maintain goal-directed engagement over time and is related to but distinguishable from other executive processes, its limited inclusion leaves unclear whether individual differences in attentional maintenance form part of the configurations of relative strengths and weaknesses observed across EF components. Second, most existing evidence is based on Western samples, leaving the generalizability of identified EF profiles across cultural contexts uncertain. Cross-cultural studies suggest that performance on directly assessed EF tasks can vary across cultural contexts, particularly for inhibitory control, although findings differ across EF components, tasks, ages, and national comparisons (Schirmbeck et al., 2020, 2021; Xu et al., 2020). Examining EF profiles among Chinese early adolescents may therefore extend current knowledge by examining the extent to which previously observed patterns are evident in a non-Western context while incorporating sustained attention alongside working memory, cognitive flexibility, response inhibition, and interference inhibition.

Executive Function, Academic Achievement, and Emotional and Behavioral Difficulties

Executive function is consistently associated with both academic achievement and emotional and behavioral difficulties. Better EF has been linked to higher achievement in mathematics, reading, and language (Best et al., 2011; Cortés Pascual et al., 2019; Spiegel et al., 2021). Among individual EF components, working memory shows particularly robust associations with academic achievement and may be especially important for mathematics, which requires students to maintain and manipulate information during multistep processing (Alloway & Alloway, 2010; Cragg & Gilmore, 2014; Peng et al., 2016). Sustained attention has likewise been associated with mathematics fluency, reading comprehension, standardized achievement, and school grades (Gallen et al., 2023; Steinmayr et al., 2010). EF is also relevant to emotional and behavioral functioning. Poorer EF prospectively predicts greater ADHD symptoms, conduct problems, depression, and broader emotional and behavioral difficulties, with inhibitory control and sustained attention particularly implicated in attention-related and behavioral problems (Martin et al., 2012; Schoemaker et al., 2013; Willcutt et al., 2005; Yang et al., 2022).

Despite this substantial variable-centered evidence, relatively few studies have examined whether EF profiles are differentially associated with academic achievement and emotional and behavioral difficulties. Existing person-centered studies generally indicate that children and adolescents with stronger EF profiles show better academic functioning, whereas profiles characterized by broad or selective EF weaknesses are associated with poorer reading and mathematics achievement (Carriedo et al., 2024; Chaku et al., 2021; Devlin et al., 2024; Litkowski et al., 2020; Relyea et al., 2023). Evidence for emotional and behavioral difficulties is more limited. In a large community sample, youth characterized by broadly low EF showed higher levels of externalizing, attention, thought, and social problems one year later, whereas differences in internalizing problems were less consistent (Chaku et al., 2022). Studies of

younger or higher-risk children have similarly linked less favorable EF profiles to poorer social functioning and greater behavioral difficulties (Cumming et al., 2023; Williams & Bentley, 2021).

Several questions nevertheless remain. Previous person-centered studies have often examined broad academic functioning or focused on one or two academic domains, leaving unclear whether differences across EF profiles extend similarly across school subjects. This question is particularly relevant to learning because academic domains differ in the extent to which they draw on particular executive processes (Cortés Pascual et al., 2019; Spiegel et al., 2021). Evidence concerning emotional and behavioral difficulties is also comparatively sparse in community samples of early adolescents, with much of the available work focusing on younger, disadvantaged, or higher-risk populations (Chaku et al., 2022; Cumming et al., 2023; Williams & Bentley, 2021). Moreover, few studies have examined subject-specific academic achievement and emotional and behavioral difficulties within the same sample. Examining both sets of outcomes may clarify whether particular EF profiles are associated with difficulties across domains or with more specific patterns of academic and behavioral functioning. Accordingly, the present study examined differences across EF profiles in school-recorded achievement in Chinese, English, and mathematics and in parent-rated emotional and behavioral difficulties among Chinese early adolescents.

Current Study

Although previous studies have identified distinct EF profiles in children and adolescents, less is known about how sustained attention is configured alongside other EF components and whether such configurations are differentially associated with academic achievement and emotional and behavioral difficulties in early adolescence. The present study addressed two aims in a school-based sample of Chinese fifth-grade students. First, latent profile analysis was used to identify EF profiles across five directly assessed indicators: working memory, cognitive flexibility, response inhibition, interference inhibition, and sustained attention. Based on previous person-centered research, we expected to identify profiles reflecting broadly high, average, and low levels of EF, while allowing for the possibility of more uneven profiles characterized by relative strengths or weaknesses across EF domains. Second, we examined whether the identified profiles differed in school-recorded achievement in Chinese, English, and mathematics and in parent-rated emotional and behavioral difficulties. We hypothesized that profiles characterized by broadly stronger EF would show higher academic achievement and fewer emotional and behavioral difficulties than profiles characterized by broadly weaker EF. Given limited prior evidence regarding domain-specific differences, variation across individual school subjects and specific emotional and behavioral difficulties, particularly for any uneven EF profiles, was examined exploratorily.

Methods

Participants

A total of 489 fifth-grade students (*M*age = 11.27, *SD* = 0.38; 46.63% female) were recruited from a public primary school in Guizhou Province, China. All students completed the computerized cognitive tasks, and school-recorded academic achievement data were available for 483 students. Parent-reported Strengths and Difficulties Questionnaire (SDQ) data were available for 255 students (*M*age = 11.28, *SD* = 0.36; 50.59% female). Parent-report data were unavailable for the remaining students because some parents declined to complete the questionnaire due to privacy concerns. Students with and without parent-reported SDQ data did not differ significantly in age or sex ($p > 0.05$).

Procedure

Data were collected in the school setting. Students individually completed five computerized cognitive tasks on school computers, with the full task battery taking approximately 45 min. The tasks assessed sustained attention, interference inhibition, response inhibition, working memory, and cognitive flexibility. Students' academic achievement in Chinese, English, and mathematics was obtained from school records. For the questionnaire subsample, parents completed the Chinese parent-report version of the SDQ through an online survey to assess their child's emotional and behavioral difficulties.

Measures

Executive function tasks

Five computerized tasks were administered. For each task, one theoretically central performance index was selected for the main analysis.

AX-continuous performance task (AX-CPT). Sustained attention and context maintenance were assessed using a child-friendly version of the AX-CPT (Fig. 1a; Li et al., 2025; Lin et al., 1999). In each trial, an A or B cue (i.e., crab or stingray) was presented at the center of the screen for 500 ms, followed by a 750 ms interstimulus interval. An X or Y probe (i.e., starfish or seashell) then appeared, and participants were required to respond within 6000 ms. Participants were instructed to press the left key only on AX trials and the right key on all other trial types (i.e., AY, BX, and BY trials). The intertrial interval varied randomly between 800 and 1200 ms. The task consisted of two blocks of 30 trials, with each block including 12 AX trials and 6 trials of each remaining trial type. Before the formal task, participants completed eight practice trials. The primary outcome measure was *d'*-context, calculated as the difference between the z-transformed corrected AX hit rate and the BX false-alarm rate (Gonthier et al., 2016).

INSERT FIGURES 1a-1e HERE

Flanker task. Interference inhibition was assessed using a child-friendly flanker task in which directional fish served as the target and flankers (Fig. 1b; Eriksen & Eriksen, 1974). A horizontal row of five fish was presented on each trial, and participants were instructed to indicate the direction of the central fish (i.e., the third fish) by pressing the left or right key while ignoring the flanking fish. The display remained

visible until a response was made or until 3000 ms had elapsed. The intertrial interval varied randomly between 400 and 600 ms. The task consisted of four blocks of 20 trials each, with equal numbers of congruent and incongruent trials. Participants completed eight practice trials before the formal task. Task performance was indexed by the reaction-time interference effect, defined as the difference between mean reaction times on incongruent and congruent trials (Eriksen & Eriksen, 1974).

Stop-signal task. A child-friendly version of the stop-signal task was used to assess response inhibition (Fig. 1c; Logan et al., 1984). A fish stimulus was presented at the center of the screen. On go trials, participants indicated its direction by pressing the left or right key. On stop trials, a fishing-net stop signal appeared after a variable stop-signal delay (SSD), instructing participants to withhold their response. The SSD was adjusted dynamically using a tracking procedure, increasing by 50 ms after successful inhibition and decreasing by 50 ms after failed inhibition, with a lower bound of 50 ms and an upper bound of 500 ms. The intertrial interval varied randomly between 800 and 1200 ms. The task comprised four blocks of 24 trials each, with stop trials occurring on 25% of trials, and participants completed eight practice trials before the formal task. Inhibitory control was indexed by stop-signal reaction time (SSRT) estimated via the integration method (Verbruggen et al., 2019).

Backward digit span task. A child-friendly version of the backward digit span task was administered to assess working memory (Fig. 1d; Wechsler, 2014). Digits were presented serially at the center of the screen for 750 ms each, and participants were instructed to reproduce each sequence in reverse order. The task began with two-digit sequences and followed an adaptive rule whereby sequence length increased by one digit when participants responded correctly to at least two of three trials at a given length. The primary outcome measure was the maximum backward span, defined as the longest sequence length at which the participant correctly recalled at least two of three trials (De Smedt et al., 2009).

Wisconsin card sorting task (WCST). Cognitive flexibility was measured using a child-friendly version of the WCST (Fig. 1e; Greve, 2001). Participants were instructed to match each response card to one of the stimulus cards according to a hidden sorting rule, using trial-by-trial feedback. The sorting rules were based on three stimulus dimensions: quantity (1, 2, 3, or 4), shape (triangle, star, cross, or circle), and color (red, green, yellow, or blue). The response card remained on the screen until a response was made or up to 6000 ms, followed by feedback on response accuracy for 2000 ms. A total of 64 response cards were administered. Task performance was indexed by the number of completed categories (Greve, 2001).

Academic achievement

Academic achievement was operationalized as students' midterm examination scores in Chinese, English, and mathematics. All scores ranged from 0 to 100 and were obtained from school-administered standardized grade-level examinations covering the standard fifth-grade curriculum in each subject.

SDQ

Children's emotional and behavioral difficulties were assessed using the Chinese parent-report version of the Strengths and Difficulties Questionnaire (SDQ; Du et al., 2008; Goodman, 2001). The SDQ includes five 5-item subscales assessing hyperactivity/inattention, emotional symptoms, conduct problems, peer problems, and prosocial behavior. Items were rated on a 3-point scale. Subscale scores were computed by summing the corresponding items, and a total difficulties score was calculated by summing the four difficulties subscales and excluding prosocial behavior. In this study, the McDonald's ω coefficients were acceptable for total difficulties (ω = 0.89), hyperactivity/inattention (ω = 0.74), emotional symptoms (ω = 0.78), prosocial behavior (ω = 0.86), conduct problems (ω = 0.75), and peer problems (ω = 0.77).

Statistical Analyses

Statistical analyses proceeded in three steps: descriptive statistics and Pearson correlations, latent profile analysis (LPA), and profile-based comparisons using one-way analyses of variance (ANOVAs). All statistical analyses were conducted using *R 4.5.0* (R Core Team, 2025).

Descriptive statistics and Pearson correlation analyses. Descriptive statistics were computed for all study variables. Means and standard deviations summarized the five EF indicators, academic achievement, and SDQ scores. Pearson correlations were then used to examine bivariate associations among the study variables. Correlations involving SDQ scores were based on the subsample with available parent-report data. Correlation coefficients were interpreted using conventional effect size guidelines, and statistical significance was evaluated using two-tailed tests (Cohen et al., 2013).

Latent Profile Analysis. LPA was conducted using the tidyLPA package, and solutions with two to five profiles were estimated under Model 1 (Rosenberg et al., 2018). LPA is a person-centered mixture-modeling approach that identifies unobserved subgroups of individuals based on continuous indicators (Pastor et al., 2007; Spurk et al., 2020). In the present study, the five EF measures were specified as profile indicators and standardized prior to analysis. The Flanker interference effect and SSRT were reverse-scored so that higher values consistently reflected better performance across all indicators. The number of profiles to retain was evaluated using the log-likelihood (LL), Akaike information criterion (AIC), Bayesian information criterion (BIC), consistent Akaike information criterion (CAIC), sample-size-adjusted BIC (SABIC), entropy, and the bootstrap likelihood ratio test (BLRT). Better fit was indicated by a higher LL value and lower AIC, BIC, CAIC, and SABIC values, and a significant BLRT (Nylund et al., 2007; Tein et al., 2013). Entropy values above 0.70 indicated acceptable classification accuracy, and values above 0.80 indicated good classification quality (Wang et al., 2017). The final solution was selected by considering model fit, classification accuracy, parsimony, profile size, and substantive interpretability together (Masyn, 2013; Spurk et al., 2020).

Profile comparisons. After the final profile solution was selected, one-way ANOVAs were used to examine whether the profiles differed across the five standardized EF indicators. These analyses were conducted to characterize the distinctiveness of the profiles and to clarify which EF domains contributed to profile separation. Profile differences in academic achievement and parent-reported SDQ scores were then examined. Academic achievement was assessed using raw scores in Chinese, English, and

mathematics. In the parent-report subsample, profile differences were also tested for each SDQ dimension and the total difficulties score. Significant omnibus effects were followed by Bonferroni-adjusted pairwise comparisons (McHugh, 2011).

Results

Descriptive statistics and Pearson correlation analyses

Descriptive statistics for the study variables are presented in Table 1. Pearson correlations among EF indicators, academic achievement, and SDQ scores are shown in Fig. 2. The EF indicators were modestly intercorrelated. Sustained attention, working memory, and cognitive flexibility were positively associated with one another, whereas interference inhibition and response inhibition showed weak associations with the other EF indicators. Regarding academic achievement, better sustained attention, working memory, and cognitive flexibility were associated with higher Chinese, English, and mathematics scores. Better interference inhibition was associated with higher English and mathematics scores, whereas better response inhibition was associated with higher scores in all three subjects. For SDQ scores, lower sustained attention and working memory scores were associated with higher hyperactivity/inattention and peer problems, and lower sustained attention scores were also associated with higher total difficulties.

Table 1
Descriptive statistics for study variables

Measures		N	M	SD
Sustained attention	AX-continuous performance task	489	3.05[a]	0.93
Interference inhibition	Flanker task		64.30[b]	104.10
Response inhibition	Stop-signal task		486.11[c]	191.91
Working memory	Backward digit span task		3.81[d]	1.66
Cognitive flexibility	Wisconsin card sorting task		2.12[e]	1.36
Academic achievement	Chinese	483	60.34	15.67
	English		67.50	21.26
	Mathematics		56.54	24.98
Hyperactivity/inattention	Hyperactivity/inattention subscale	255	3.35	1.96
Emotional symptoms	Emotional symptoms subscale		2.38	2.09
Conduct problems	Conduct problems subscale		1.69	1.32
Peer problems	Peer problems subscale		2.44	1.61
Prosocial behavior	Prosocial behavior subscale		7.58	2.03
Total difficulties	Strengths and difficulties questionnaire		9.87	5.09

Note. M = Mean, *SD* = Standard deviation, a = *d'*-context, b = reaction-time interference effect, c = stop-signal reaction time, d = maximum backward span, e = the number of completed categories.

INSERT Table 1 HERE

INSERT FIGURE 2 HERE

Latent Profile Analysis

LPA was conducted using the five standardized EF indicators, with all scores coded such that higher values indicated better performance, allowing profile means to be interpreted relative to the sample average. A stepwise model-comparison approach was used to identify the solution that best characterized heterogeneity in EF performance. Specifically, models with two to five profiles were estimated and compared using LL, AIC, BIC, CAIC, SABIC, entropy, and BLRT, as shown in Table 2. The three-profile solution provided the most favorable fit, as the BIC, CAIC, and SABIC reached their lowest values for this solution, and the BLRT was significant for the three-profile model ($p = 0.04$) but not for the four-profile model ($p = 0.15$), indicating that adding a fourth profile did not significantly improve model fit.

The three-profile solution also showed acceptable classification quality, as indicated by an entropy of 0.78 and average posterior probabilities (AvePP) of 0.83, 0.91, and 0.97 for Profiles 1–3, respectively.

Table 2
Fit indices for latent profile models

Model	LL	AIC	BIC	CAIC	SABIC	Entropy	BLRT *p*-value
2-profile	-3318.21	6668.42	6735.50	6751.50	6684.71	0.98	< .001
3-profile	**-3296.39**	**6636.78**	**6729.01**	**6751.01**	**6659.18**	**0.78**	**0.04**
4-profile	-3289.62	6635.25	6752.63	6780.63	6663.76	0.63	0.15
5-profile	-3278.98	6625.95	6768.49	6802.49	6660.58	0.70	0.12

Note. Bolded values indicate preferred model for a given fit index.

LL = Log-likelihood, *AIC* = Akaike Information Criteria, *BIC* = Bayesian information criterion, *CAIC* = Consistent akaike information criterion, *SABIC* = Sample-adjusted Bayesian information criterion, *BLRT* = Bootstrap likelihood ratio test.

INSERT Table 2 HERE

The three profiles differed in both overall level and configuration of EF indicators. Profile 1 (n = 101, 20.65%) was characterized by relatively high performance across most indicators, particularly working memory, and was labeled High EF. Profile 2 (n = 344, 70.35%), the largest group, showed generally average performance across indicators and was labeled Average EF. Profile 3 (n = 44, 9.00%) was distinguished by a considerable weakness in sustained attention, accompanied by generally lower performance on the remaining EF indicators. This profile was therefore labeled Attention-vulnerable EF, reflecting a qualitatively meaningful vulnerability centered on attention-related control rather than a uniformly low EF pattern. The standardized profile patterns are presented in Fig. 3a.

INSERT FIGURES 3a-3b HERE

To characterize how the profiles differed on the defining indicators, one-way ANOVAs compared the three profiles across the five EF indicators (Fig. 3b). Significant profile differences emerged for all indicators, including sustained attention, $F(2, 486) = 526.68$, $p < 0.001$, $\eta^2 = 0.68$; working memory, $F(2, 486) = 297.91$, $p < 0.001$, $\eta^2 = 0.55$; cognitive flexibility, $F(2, 486) = 21.25$, $p < 0.001$, $\eta^2 = 0.08$; interference inhibition, $F(2, 486) = 7.70$, $p < 0.001$, $\eta^2 = 0.03$; and response inhibition, $F(2, 486) = 3.82$, $p = 0.02$, $\eta^2 = 0.02$.

Bonferroni-adjusted post hoc comparisons revealed a clear and differentiated pattern. For sustained attention, the Attention-vulnerable EF profile scored substantially lower than both the High EF profile, $t(486) = 28.79$, $p < 0.001$, Cohen's $d = 5.20$, and the Average EF profile, $t(486) = 31.89$, $p < 0.001$, Cohen's d

= 5.11, whereas the High EF and Average EF profiles did not differ, $t(486) = 0.83$, $p = 1.00$, Cohen's $d = 0.09$. For working memory, the High EF profile outperformed both the Average EF profile, $t(486) = 23.99$, $p < 0.001$, Cohen's $d = 2.72$, and the Attention-vulnerable EF profile, $t(486) = 15.56$, $p < 0.001$, Cohen's $d = 2.81$, with no significant difference between the Average and Attention-vulnerable EF profiles, $t(486) = 0.60$, $p = 1.00$, Cohen's $d = 0.10$. A similar pattern was observed for cognitive flexibility, such that the High EF profile scored higher than both the Average EF profile, $t(486) = 6.21$, $p < 0.001$, Cohen's $d = 0.70$, and the Attention-vulnerable EF profile, $t(486) = 4.74$, $p < 0.001$, Cohen's $d = 0.86$, while the latter two profiles did not differ, $t(486) = 0.96$, $p = 1.00$, Cohen's $d = 0.15$. For interference inhibition, the *High EF* profile also scored higher than the Average EF profile, $t(486) = 3.40$, $p = 0.002$, Cohen's $d = 0.39$, and the Attention-vulnerable EF profile, $t(486) = 3.36$, $p = 0.003$, Cohen's $d = 0.61$, whereas the Average EF and Attention-vulnerable EF profiles did not significantly differ, $t(486) = 1.39$, $p = 0.50$, Cohen's $d = 0.22$. Finally, for response inhibition, the Attention-vulnerable EF profile scored lower than both the High EF profile, $t(486) = 2.57$, $p = 0.03$, Cohen's $d = 0.46$, and the Average EF profile, $t(486) = 2.65$, $p = 0.03$, Cohen's $d = 0.42$, while the High EF and Average EF profiles did not differ, $t(486) = 0.35$, $p = 1.00$, Cohen's $d = 0.04$. Taken together, these findings indicate that the three-profile solution captured meaningful heterogeneity in early adolescents' EF performance.

Differences in academic achievement and SDQ scores across latent profiles

To further characterize the EF profiles, the three profiles were compared on academic achievement and parent-reported SDQ scores. One-way ANOVAs revealed significant profile differences across all three academic subjects: mathematics, $F(2, 480) = 26.32$, $p < 0.001$, $\eta^2 = 0.10$; Chinese, $F(2, 480) = 16.04$, $p < 0.001$, $\eta^2 = 0.06$; and English, $F(2, 480) = 16.23$, $p < 0.001$, $\eta^2 = 0.06$. Bonferroni-adjusted post hoc comparisons showed that early adolescents in the High EF profile scored significantly higher than those in the Average EF profile in mathematics, $t(480) = 6.11$, $p < 0.001$, Cohen's $d = 0.69$; Chinese, $t(480) = 5.20$, $p < 0.001$, Cohen's $d = 0.59$; and English, $t(480) = 4.75$, $p < 0.001$, Cohen's $d = 0.54$. They also outperformed those in the Attention-vulnerable EF profile in mathematics, $t(480) = 6.38$, $p < 0.001$, Cohen's $d = 1.15$; Chinese, $t(480) = 4.48$, $p < 0.001$, Cohen's $d = 0.81$; and English, $t(480) = 5.05$, $p < 0.001$, Cohen's $d = 0.91$. The Average EF profile scored higher than the Attention-vulnerable EF profile only in mathematics, $t(480) = 2.87$, $p = 0.01$, Cohen's $d = 0.46$, but not in Chinese, $t(480) = 1.36$, $p = 0.52$, Cohen's $d = 0.22$, or English, $t(480) = 2.34$, $p = 0.06$, Cohen's $d = 0.38$. Thus, the academic results showed a robust advantage for the High EF profile across subjects, whereas the distinction between the Average EF and Attention-vulnerable EF profiles was most evident in mathematics (Fig. 4a).

INSERT FIGURES 4a-4b HERE

Significant profile differences also emerged for three SDQ domains: hyperactivity/inattention, $F(2, 252) = 4.89$, $p = 0.008$, $\eta^2 = 0.037$; peer problems, $F(2, 252) = 7.55$, $p < 0.001$, $\eta^2 = 0.057$; and total difficulties, $F(2, 252) = 5.88$, $p = 0.003$, $\eta^2 = 0.045$. Profile differences were not significant for emotional symptoms, $F(2, 252) = 0.87$, $p = 0.421$, $\eta^2 = 0.007$; conduct problems, $F(2, 252) = 1.71$, $p = 0.182$, $\eta^2 = 0.013$, or prosocial

behavior, $F(2, 252) = 2.01$, $p = 0.136$, $\eta^2 = 0.016$. Bonferroni-adjusted post hoc comparisons indicated that early adolescents in the Attention-vulnerable EF profile showed higher hyperactivity/inattention than those in the High EF profile, $t(252) = 3.12$, $p = 0.006$, Cohen's $d = 0.83$, and the Average EF profile, $t(252) = 2.47$, $p = 0.04$, Cohen's $d = 0.61$. The same pattern emerged for peer problems, with the Attention-vulnerable EF profile scoring higher than both the High EF profile, $t(252) = 3.84$, $p < 0.001$, Cohen's $d = 1.02$, and the Average EF profile, $t(252) = 3.09$, $p = 0.007$, Cohen's $d = 0.77$. For total difficulties, the Attention-vulnerable EF profile again scored higher than the High EF profile, $t(252) = 3.42$, $p = 0.002$, Cohen's $d = 0.91$, and the Average EF profile, $t(252) = 2.77$, $p = 0.02$, Cohen's $d = 0.69$. In contrast, the High EF and Average EF profiles did not differ significantly in hyperactivity/inattention, $t(252) = 1.49$, $p = 0.41$, Cohen's $d = 0.22$; peer problems, $t(252) = 1.77$, $p = 0.24$, Cohen's $d = 0.26$; or total difficulties, $t(252) = 1.55$, $p = 0.37$, Cohen's $d = 0.23$. These findings suggest that the Attention-vulnerable EF profile was specifically associated with elevated attention-related difficulties (Fig. 4b).

Discussion

Although executive function (EF) has been extensively linked to academic achievement and emotional and behavioral difficulties, relatively little is known about the heterogeneity of EF configurations in early adolescence and whether adolescents with different EF profiles differ in academic achievement and emotional and behavioral difficulties. The present study addressed these gaps by identifying EF profiles among Chinese early adolescents and examining differences across profiles in academic achievement and emotional and behavioral difficulties. Three profiles emerged: High EF, Average EF, and Attention-vulnerable EF. Adolescents in the High EF profile showed higher achievement in Chinese, English, and mathematics than those in the other two profiles. Compared with the Average EF profile, adolescents in the Attention-vulnerable EF profile showed lower mathematics achievement and higher hyperactivity/inattention, peer problems, and total difficulties. Together, these findings suggest that EF heterogeneity in early adolescence involves both differences in overall executive functioning and more specific configurations of relative strengths and weaknesses, with distinct associations across academic and behavioral domains.

Heterogeneity in EF Profiles among Chinese Early Adolescents

The three-profile solution suggests that EF heterogeneity was organized along both overall level and relative configuration. The High EF and Average EF profiles differed primarily in working memory, cognitive flexibility, and interference inhibition, whereas the Attention-vulnerable EF profile combined generally lower performance with a disproportionate weakness in sustained attention and a less pronounced weakness in response inhibition. The High EF pattern may reflect stronger goal-maintenance-based control, as working memory, cognitive flexibility, and interference inhibition all rely on maintaining and flexibly using goal-relevant information to guide ongoing processing (Braver, 2012; Friedman & Miyake, 2017). In contrast, response inhibition depends more strongly on the reactive

cancellation of an initiated response and may therefore vary less closely with these processes (Braver, 2012; Friedman & Miyake, 2004; Verbruggen et al., 2019). Overall, this pattern is consistent with the view that EF components share common control demands while retaining component-specific variation (Friedman & Miyake, 2017; Miyake & Friedman, 2012).

A key finding was the identification of the Attention-vulnerable EF profile, which showed a generally weaker EF pattern with sustained attention as its most pronounced weakness. Previous person-centered studies have identified broadly low profiles and uneven profiles centered on working memory, cognitive flexibility, or inhibition, whereas sustained attention has generally been omitted or incorporated into broader constructs rather than modeled as a distinct profile indicator (Brandt et al., 2024; Carriedo et al., 2024; Chaku et al., 2022; Usai et al., 2018; Younger et al., 2024). This omission matters because broader accounts place attention regulation within EF, and empirical evidence indicates that sustained attention is related to but distinguishable from canonical EF processes, with a particular demand for maintaining goal-directed engagement over time (Blair, 2016; Deodhar & Bertenthal, 2023; Unsworth & Robison, 2020). The present profile is therefore consistent with the possibility that individual differences in attentional maintenance are not fully aligned with variation in canonical EF components. The profile therefore suggests that models of EF heterogeneity should consider not only overall proficiency and relative strengths and weaknesses across canonical components, but also the maintenance of goal-directed attention over time. By identifying this pattern among Chinese early adolescents, the study broadens the predominantly Western evidence base and supports considering sustained attention as a distinct indicator in person-centered models of executive functioning.

Academic Achievement and Emotional and Behavioral Difficulties across EF Profiles

Adolescents in the High EF profile outperformed both other profiles in Chinese, English, and mathematics, extending previous person-centered evidence of stronger academic functioning in favorable EF profiles to multiple school subjects among Chinese early adolescents (Carriedo et al., 2024; Chaku et al., 2021; Litkowski et al., 2020; Relyea et al., 2023). This profile combined stronger working memory, cognitive flexibility, and interference inhibition, with working memory showing the largest relative elevation. The cross-subject advantage should therefore be interpreted in relation to the broader configuration of executive strengths rather than attributed to any single component. Notably, however, the High EF and Average EF profiles did not differ significantly on any SDQ dimension, suggesting that the distinction between these two profiles was more evident in academic achievement than in emotional and behavioral difficulties.

In contrast, the Attention-vulnerable EF profile showed a more selective pattern of difficulty. Compared with the Average EF profile, these adolescents had lower mathematics achievement and higher parent-reported hyperactivity/inattention. The same profile contrast was not statistically significant for Chinese or English achievement, indicating that the academic difference between these two profiles was most evident in mathematics rather than uniformly across school subjects. This pattern may partly reflect the

sustained goal-directed control required during multistep mathematical processing. Sustained attention supports continued task engagement and maintains the priority of goal-relevant information during ongoing processing (Petersen & Posner, 2012; Unsworth & Robison, 2020). Mathematics may be especially sensitive to disruptions in this continuity because multistep solutions require intermediate results and procedural steps to remain coordinated, such that a lapse at one stage can compromise subsequent operations (Cragg & Gilmore, 2014; Gallen et al., 2023; Peng et al., 2016). In everyday settings, difficulties sustaining attention and regulating responses may be expressed as inattention, inconsistent task engagement, and hyperactive or impulsive behavior (Martin et al., 2012; Schoemaker et al., 2013; Willcutt et al., 2005).

The Attention-vulnerable EF profile also showed greater peer problems. Peer interaction requires ongoing monitoring of changing social cues and adjustment of behavior within reciprocal exchanges, making peer functioning another context in which attention and self-regulatory vulnerabilities may become evident (Chaku et al., 2022; Cumming et al., 2023). No profile differences emerged in emotional symptoms, conduct problems, or prosocial behavior. The absence of differences in emotional symptoms is consistent with previous person-centered evidence showing less robust associations of EF profiles with internalizing than with attention-related and social difficulties (Chaku et al., 2022). The higher total difficulties score therefore appears to reflect the specific elevations in hyperactivity/inattention and peer problems rather than generalized emotional and behavioral maladjustment.

Limitations and Future Directions

Several limitations should be noted. First, parent-reported SDQ data were available for a subset of participants, and emotional and behavioral difficulties were assessed from a single informant. Future studies could aim to align questionnaire coverage more closely with the full task sample and incorporate teacher reports to examine whether the observed attention-related and peer difficulties are evident across home and school contexts. Second, the cross-sectional design and narrow age range provide a focused view of EF profiles in fifth grade but do not capture their developmental stability, transitions between profiles, or the temporal ordering between EF configurations and their associated outcomes. Recruitment from a single school may also constrain the generalizability of the findings across regional and educational contexts. In addition, general cognitive ability and family socioeconomic status were not included, and their potential contributions therefore remain to be examined. Future longitudinal and multisite studies should investigate profile stability and developmental transitions and test whether the observed associations remain robust after accounting for broader cognitive and contextual factors.

Implications

The educational implications point toward the potential value of differentiated rather than uniform support. Across subjects, instruction that makes task goals and intermediate information visible, structures complex activities to reduce unnecessary demands on working memory, and makes strategy shifts and progress monitoring explicit may be useful for students with different EF configurations. More targeted support may be particularly relevant in mathematics for students with attention-centered

vulnerabilities. Candidate strategies for future evaluation include segmenting multistep problems, externalizing intermediate results, and embedding brief monitoring prompts to support continuity across sequentially dependent operations (Cragg & Gilmore, 2014; Peng et al., 2016). Because attention-centered vulnerabilities may also be evident in classroom behavior and peer interaction, support may need to extend beyond academic tasks to classroom routines and collaborative activities that require sustained engagement and behavioral regulation. Future school-based research should examine whether tailoring the focus and intensity of support to different EF configurations produces greater academic and behavioral benefits than uniform approaches.

Conclusion

Although EF comprises multiple interrelated components, less is known about how these components are configured within early adolescents and whether adolescents with different EF profiles differ in academic achievement and emotional and behavioral difficulties. Using a person-centered approach, this study examined EF profiles among Chinese early adolescents based on working memory, cognitive flexibility, response inhibition, interference inhibition, and sustained attention, as well as profile differences in school-recorded academic achievement and parent-rated emotional and behavioral difficulties. Three profiles were identified: High EF, Average EF, and Attention-vulnerable EF. Adolescents in the High EF profile showed higher achievement in Chinese, English, and mathematics than those in the other profiles. Compared with the Average EF profile, adolescents in the Attention-vulnerable EF profile showed lower mathematics achievement and greater hyperactivity/inattention and peer problems. These findings indicate that individual differences in EF during early adolescence involve both overall levels of functioning and specific configurations of relative strengths and weaknesses, and that these configurations may correspond to different patterns of academic and behavioral functioning.

Declarations

Data availability

The datasets generated during and/or analysed during the current study are not publicly available because they contain sensitive information collected from minor participants, and unrestricted public sharing could compromise participant privacy and raise ethical concerns, but are available from the corresponding author on reasonable request and subject to relevant ethical requirements.

Code availability

The analysis code used in the current study is available at https://github.com/HuiLee-Psy/EF-LPA-analysis.

Funding

This research was supported by STI 2030–the Major Projects (2021ZD0200500 & 2021ZD0204300), and the Key Program of National Natural Science Foundation of China (61632014).

Acknowledgements

The authors thank all students who participated in the study.

Author contributions

Hui Li: Conceptualization, Methodology, Software, Formal analysis, Visualization, Writing–original draft preparation, Writing–review & editing, Resources. **Yiting Liang:** Methodology, Writing–review & editing. **Jurong Xue:** Writing–review & editing, Resources. **Kaiyu Gan:** Methodology. **Sai Ma:** Software, Writing–review & editing. **Wei Liu:** Resources. **Zijie Qin:** Software. **Shiyu Fang:** Resources. **Xuemin Zhang:** Funding acquisition, Supervision.

Competing interests

The authors declare no competing interests.

Ethics declarations

The study protocol and procedures were approved by the Research Ethics Committee of Beijing Normal University (IRB Number: BNU202504210121). All methods were carried out in accordance with the Declaration of Helsinki and relevant institutional guidelines and regulations. Written informed consent was obtained from parents or legal guardians before participation. Students were informed that participation was voluntary and that they could decline to participate or withdraw from the study at any time.

References

1. Alloway TP, Alloway RG (2010) Investigating the predictive roles of working memory and IQ in academic attainment. J Exp Child Psychol 106(1):20–29. https://doi.org/10.1016/j.jecp.2009.11.003
2. Banich MT (2009) Executive function. Curr Dir Psychol Sci 18(2):89–94. https://doi.org/10.1111/j.1467-8721.2009.01615.x
3. Bergman LR, Magnusson D (1997) A person-oriented approach in research on developmental psychopathology. Dev Psychopathol 9(2):291–319. https://doi.org/10.1017/S095457949700206X
4. Bergman LR, Magnusson D, El Khouri BM (2003) Studying individual development in an interindividual context: A person-oriented approach. Psychology Press. https://doi.org/10.4324/9781410606822
5. Best JR, Miller PH, Naglieri JA (2011) Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. Learn Individ Differ

21(4):327–336. https://doi.org/10.1016/j.lindif.2011.01.007

6. Blair C (2016) Executive function and early childhood education. Curr Opin Behav Sci 10:102–107. https://doi.org/10.1016/j.cobeha.2016.05.009
7. Brandt A, Bondü R, Elsner B (2024) Profiles of executive functions in middle childhood and prediction of later self-regulation. Front Psychol 15:1379126. https://doi.org/10.3389/fpsyg.2024.1379126
8. Braver TS (2012) The variable nature of cognitive control: A dual mechanisms framework. Trends Cogn Sci 16(2):106–113. https://doi.org/10.1016/j.tics.2011.12.010
9. Carriedo N, Rodríguez-Villagra OA, Pérez L, Iglesias-Sarmiento V (2024) Executive functioning profiles and mathematical and reading achievement in Grades 2, 6, and 10. J Sch Psychol 106:101353. https://doi.org/10.1016/j.jsp.2024.101353
10. Chaku N, Barry K, Fowle J, Hoyt LT (2022) Understanding patterns of heterogeneity in executive functioning during adolescence: Evidence from population-level data. Dev Sci 25(6):e13256. https://doi.org/10.1111/desc.13256
11. Chaku N, Hoyt LT, Barry K (2021) Executive functioning profiles in adolescence: Using person-centered approaches to understand heterogeneity. Cogn Dev 60:101119. https://doi.org/10.1016/j.cogdev.2021.101119
12. Cohen J, Cohen P, West SG, Aiken LS (2013) Applied multiple regression/correlation analysis for the behavioral sciences, 3rd edn. Routledge. https://doi.org/10.4324/9780203774441
13. Cortés Pascual A, Moyano Muñoz N, Quílez Robres A (2019) The relationship between executive functions and academic performance in primary education: Review and meta-analysis. Front Psychol 10:1582. https://doi.org/10.3389/fpsyg.2019.01582
14. Cragg L, Gilmore C (2014) Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. Trends Neurosci Educ 3(2):63–68. https://doi.org/10.1016/j.tine.2013.12.001
15. Cumming MM, Poling DV, Qiu Y, Prykanowski DA, Lumpkins A, Daunic AP, Corbett N, Smith SW (2023) Executive function profiles of kindergarteners and first graders at risk for emotional and behavioral disorders. Except Child 89(3):294–313. https://doi.org/10.1177/00144029221135573
16. Deodhar AV, Bertenthal BI (2023) How attention factors into executive function in preschool children. Front Psychol 14:1146101. https://doi.org/10.3389/fpsyg.2023.1146101
17. De Smedt B, Janssen R, Bouwens K, Verschaffel L, Boets B, Ghesquière P (2009) Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. J Exp Child Psychol 103(2):186–201. https://doi.org/10.1016/j.jecp.2009.01.004
18. Devlin BL, Geer EA, Finders JK, Zehner TM, Duncan RJ, Purpura DJ, Schmitt SA (2024) Patterns of individual differences in executive functions for preschoolers from low-income backgrounds: Associations with pre-academic skills. Learn Individ Differ 114:102498. https://doi.org/10.1016/j.lindif.2024.102498

19. Diamond A (2013) Executive functions. Annu Rev Psychol 64:135–168. https://doi.org/10.1146/annurev-psych-113011-143750
20. Du Y, Kou J, Coghill D (2008) The validity, reliability and normative scores of the parent, teacher and self report versions of the Strengths and Difficulties Questionnaire in China. Child Adolesc Psychiatry Ment Health 2:8. https://doi.org/10.1186/1753-2000-2-8
21. Eriksen BA, Eriksen CW (1974) Effects of noise letters upon the identification of a target letter in a nonsearch task. Percept Psychophys 16(1):143–149. https://doi.org/10.3758/BF03203267
22. Folker A, Bertrand C, Hong Y et al (2025) A longitudinal study of adolescent-to-young adult executive function development in seven countries. Dev Sci 28(4):e70040. https://doi.org/10.1111/desc.70040
23. Friedman NP, Miyake A (2004) The relations among inhibition and interference control functions: A latent-variable analysis. J Exp Psychol Gen 133(1):101–135. https://doi.org/10.1037/0096-3445.133.1.101
24. Friedman NP, Miyake A (2017) Unity and diversity of executive functions: Individual differences as a window on cognitive structure. Cortex 86:186–204. https://doi.org/10.1016/j.cortex.2016.04.023
25. Gallen CL, Schaerlaeken S, Younger JW, Project iLEAD Consortium, Anguera JA, Gazzaley A (2023) Contribution of sustained attention abilities to real-world academic skills in children. Sci Rep 13:2673. https://doi.org/10.1038/s41598-023-29427-w
26. Gonthier C, Macnamara BN, Chow M, Conway ARA, Braver TS (2016) Inducing proactive control shifts in the AX-CPT. Front Psychol 7:1822. https://doi.org/10.3389/fpsyg.2016.01822
27. Goodman R (2001) Psychometric properties of the Strengths and Difficulties Questionnaire. J Am Acad Child Adolesc Psychiatry 40(11):1337–1345. https://doi.org/10.1097/00004583-200111000-00015
28. Greve KW (2001) The WCST-64: A standardized short-form of the Wisconsin Card Sorting Test. Clin Neuropsychol 15(2):228–234. https://doi.org/10.1076/clin.15.2.228.1901
29. Karr JE, Areshenkoff CN, Rast P, Hofer SM, Iverson GL, Garcia-Barrera MA (2018) The unity and diversity of executive functions: A systematic review and re-analysis of latent variable studies. Psychol Bull 144(11):1147–1185. https://doi.org/10.1037/bul0000160
30. Li Y, Ganesan K, Smid CR, Thompson A, Cañigueral R, Royer J, Bernhardt B, Steinbeis N (2025) Structural brain basis of latent factors of executive functions in childhood. Dev Cogn Neurosci 71:101504. https://doi.org/10.1016/j.dcn.2024.101504
31. Lin CCH, Hsiao CK, Chen WJ (1999) Development of sustained attention assessed using the Continuous Performance Test among children 6–15 years of age. J Abnorm Child Psychol 27(5):403–412. https://doi.org/10.1023/A:1021932119311
32. Litkowski EC, Finders JK, Borriello GA, Purpura DJ, Schmitt SA (2020) Patterns of heterogeneity in kindergarten children's executive function: Profile associations with third grade achievement. Learn Individ Differ 80:101846. https://doi.org/10.1016/j.lindif.2020.101846

33. Logan GD, Cowan WB, Davis KA (1984) On the ability to inhibit simple and choice reaction time responses: A model and a method. J Exp Psychol Hum Percept Perform 10(2):276–291. https://doi.org/10.1037/0096-1523.10.2.276
34. Ma J, Liu X, Pan T, Ji L, Zhang W (2026) Developmental changes in the structure of executive function from early to late adolescence. J Youth Adolesc 55(4):982–997. https://doi.org/10.1007/s10964-025-02293-7
35. Martin A, Razza RA, Brooks-Gunn J (2012) Sustained attention at age 5 predicts attention-related problems at age 9. Int J Behav Dev 36(6):413–419. https://doi.org/10.1177/0165025412450527
36. Masyn KE (2013) Latent class analysis and finite mixture modeling. In: Little TD (ed) The Oxford handbook of quantitative methods in psychology, vol 2: Statistical analysis. Oxford University Press, pp 551–611. https://doi.org/10.1093/oxfordhb/9780199934898.013.0025
37. McHugh ML (2011) Multiple comparison analysis testing in ANOVA. Biochem Med 21(3):203–209. https://doi.org/10.11613/bm.2011.029
38. Miller EK, Cohen JD (2001) An integrative theory of prefrontal cortex function. Annu Rev Neurosci 24:167–202. https://doi.org/10.1146/annurev.neuro.24.1.167
39. Miyake A, Friedman NP (2012) The nature and organization of individual differences in executive functions: Four general conclusions. Curr Dir Psychol Sci 21(1):8–14. https://doi.org/10.1177/0963721411429458
40. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD (2000) The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. Cogn Psychol 41(1):49–100. https://doi.org/10.1006/cogp.1999.0734
41. Nylund KL, Asparouhov T, Muthén BO (2007) Deciding on the number of classes in latent class analysis and growth mixture modeling: A Monte Carlo simulation study. Struct Equ Model 14(4):535–569. https://doi.org/10.1080/10705510701575396
42. Pastor DA, Barron KE, Miller BJ, Davis SL (2007) A latent profile analysis of college students’ achievement goal orientation. Contemp Educ Psychol 32(1):8–47. https://doi.org/10.1016/j.cedpsych.2006.10.003
43. Peng P, Namkung J, Barnes M, Sun C (2016) A meta-analysis of mathematics and working memory: Moderating effects of working memory domain, type of mathematics skill, and sample characteristics. J Educ Psychol 108(4):455–473. https://doi.org/10.1037/edu0000079
44. Petersen SE, Posner MI (2012) The attention system of the human brain: 20 years after. Annu Rev Neurosci 35:73–89. https://doi.org/10.1146/annurev-neuro-062111-150525
45. R Core Team (2025) R: A language and environment for statistical computing (Version 4.5.0) [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/
46. Relyea JE, Cho E, Zagata E (2023) First-grade multilingual students’ executive function profiles and links to English reading achievement and difficulties: A person-centered latent profile analysis. Ann Dyslexia 73(1):29–52. https://doi.org/10.1007/s11881-022-00272-2

47. Rey-Mermet A, Gade M, Oberauer K (2018) Should we stop thinking about inhibition? Searching for individual and age differences in inhibition ability. J Exp Psychol Learn Mem Cogn 44(4):501–526. https://doi.org/10.1037/xlm0000450
48. Robertson IH, Manly T, Andrade J, Baddeley BT, Yiend J (1997) 'Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. Neuropsychologia 35(6):747–758. https://doi.org/10.1016/S0028-3932(97)00015-8
49. Rosenberg JM, Beymer PN, Anderson DJ, van Lissa CJ, Schmidt JA (2018) tidyLPA: An R package to easily carry out latent profile analysis (LPA) using open-source or commercial software. J Open Source Softw 3(30):978. https://doi.org/10.21105/joss.00978
50. Schirmbeck K, Rao N, Maehler C (2020) Similarities and differences across countries in the development of executive functions in children: A systematic review. Infant Child Dev 29(1):e2164. https://doi.org/10.1002/icd.2164
51. Schirmbeck K, Rao N, Wang R, Richards B, Chan SWY, Maehler C (2021) Contrasting executive function development among primary school children from Hong Kong and Germany. Eur J Psychol Educ 36(4):923–943. https://doi.org/10.1007/s10212-020-00519-9
52. Schoemaker K, Mulder H, Deković M, Matthys W (2013) Executive functions in preschool children with externalizing behavior problems: A meta-analysis. J Abnorm Child Psychol 41(3):457–471. https://doi.org/10.1007/s10802-012-9684-x
53. Spiegel JA, Goodrich JM, Morris BM, Osborne CM, Lonigan CJ (2021) Relations between executive functions and academic outcomes in elementary school children: A meta-analysis. Psychol Bull 147(4):329–351. https://doi.org/10.1037/bul0000322
54. Spurk D, Hirschi A, Wang M, Valero D, Kauffeld S (2020) Latent profile analysis: A review and "how to" guide of its application within vocational behavior research. J Vocat Behav 120:103445. https://doi.org/10.1016/j.jvb.2020.103445
55. Steinmayr R, Ziegler M, Träuble B (2010) Do intelligence and sustained attention interact in predicting academic achievement? Learn Individ Differ 20(1):14–18. https://doi.org/10.1016/j.lindif.2009.10.009
56. Tein J-Y, Coxe S, Cham H (2013) Statistical power to detect the correct number of classes in latent profile analysis. Struct Equ Model 20(4):640–657. https://doi.org/10.1080/10705511.2013.824781
57. Tervo-Clemmens B, Calabro FJ, Parr AC, Fedor J, Foran W, Luna B (2023) A canonical trajectory of executive function maturation from adolescence to adulthood. Nat Commun 14:6922. https://doi.org/10.1038/s41467-023-42540-8
58. Unsworth N, Robison MK (2020) Working memory capacity and sustained attention: A cognitive-energetic perspective. J Exp Psychol Learn Mem Cogn 46(1):77–103. https://doi.org/10.1037/xlm0000712
59. Usai MC, Viterbori P, Traverso L (2018) Preschool executive function profiles: Implications for math achievement in Grades 1 and 3. J Res Child Educ 32(4):404–418. https://doi.org/10.1080/02568543.2018.1496957

60. Verbruggen F, Aron AR, Band GP et al (2019) A consensus guide to capturing the ability to inhibit actions and impulsive behaviors in the stop-signal task. eLife 8:e46323. https://doi.org/10.7554/eLife.46323
61. Wang M-C, Deng Q, Bi X, Ye H, Yang W (2017) Performance of the entropy as an index of classification accuracy in latent profile analysis: A Monte Carlo simulation study. Acta Psychol Sin 49(11):1473–1482. https://doi.org/10.3724/SP.J.1041.2017.01473
62. Wechsler D (2014) Wechsler Intelligence Scale for Children–Fifth Edition (WISC-V). Pearson
63. Willcutt EG, Doyle AE, Nigg JT, Faraone SV, Pennington BF (2005) Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. Biol Psychiatry 57(11):1336–1346. https://doi.org/10.1016/j.biopsych.2005.02.006
64. Williams KE, Bentley LA (2021) Latent profiles of teacher-reported self-regulation and assessed executive function in low-income community preschools: Relations with motor, social, and school readiness outcomes. Front Psychol 12:708514. https://doi.org/10.3389/fpsyg.2021.708514
65. Xu C, Ellefson MR, Ng FF-Y, Wang Q, Hughes C (2020) An East–West contrast in executive function: Measurement invariance of computerized tasks in school-aged children and adolescents. J Exp Child Psychol 199:104929. https://doi.org/10.1016/j.jecp.2020.104929
66. Yang Y, Shields GS, Zhang Y, Wu H, Chen H, Romer AL (2022) Child executive function and future externalizing and internalizing problems: A meta-analysis of prospective longitudinal studies. Clin Psychol Rev 97:102194. https://doi.org/10.1016/j.cpr.2022.102194
67. Younger JW, Schaerlaeken S, Anguera JA, Gazzaley A, Project iLEAD Consortium (2024) The whole is greater than the sum of its parts: Using cognitive profiles to predict academic achievement. Trends Neurosci Educ 36:100237. https://doi.org/10.1016/j.tine.2024.100237
68. Zelazo PD (2015) Executive function: Reflection, iterative reprocessing, complexity, and the developing brain. Dev Rev 38:55–68. https://doi.org/10.1016/j.dr.2015.07.001
69. Zelazo PD, Blair CB, Willoughby MT (2016) Executive function: Implications for education (NCER 2017-2000). National Center for Education Research, Institute of Education Sciences, U.S. Department of Education

Figures

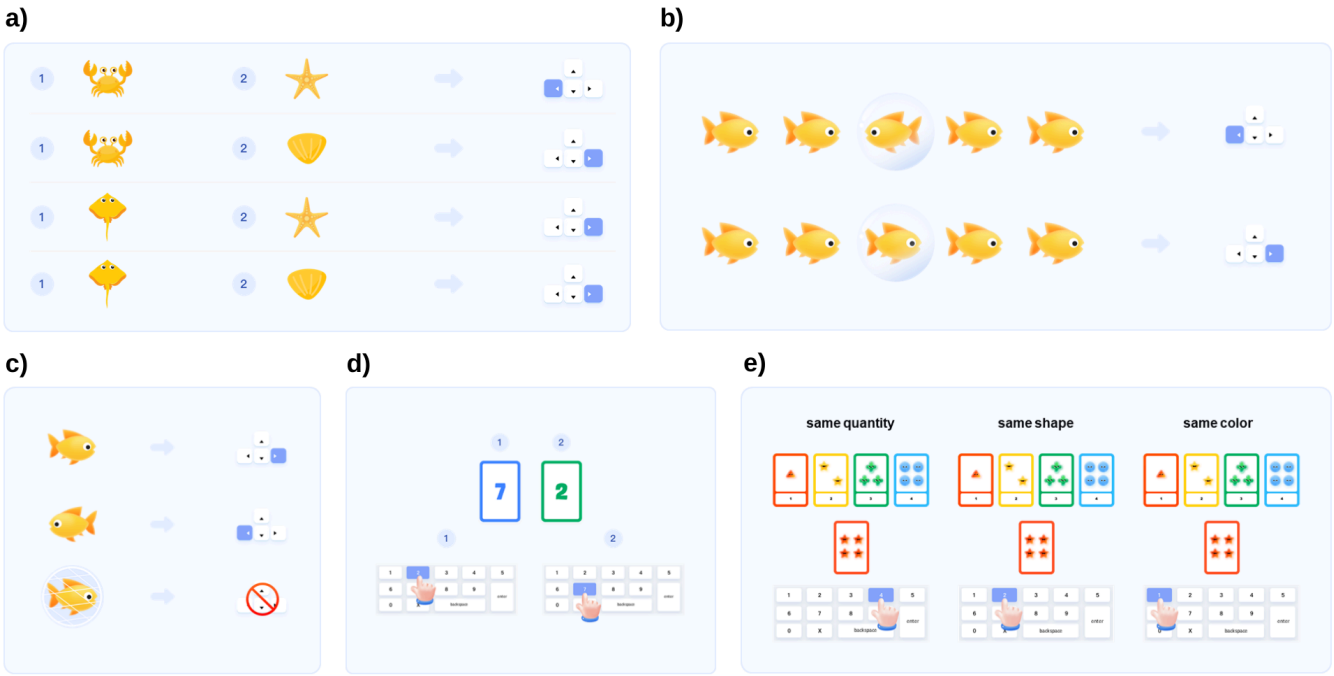


Figure 1

Task stimuli for the five EF tasks. a) AX-CPT task requiring participants to press the left key on AX trials and the right key on all other trial types. **b)** Flanker task requiring participants to indicate the direction of the central fish. **c)** Stop-signal task requiring participants to respond to the direction of the fish and to withhold their response when a fishing-net stop signal appeared. **d)** Backward digit span task requiring participants to reproduce digit sequences in reverse order. **e)** WCSTrequiring participants to sort cards by quantity, shape, or color based on feedback.

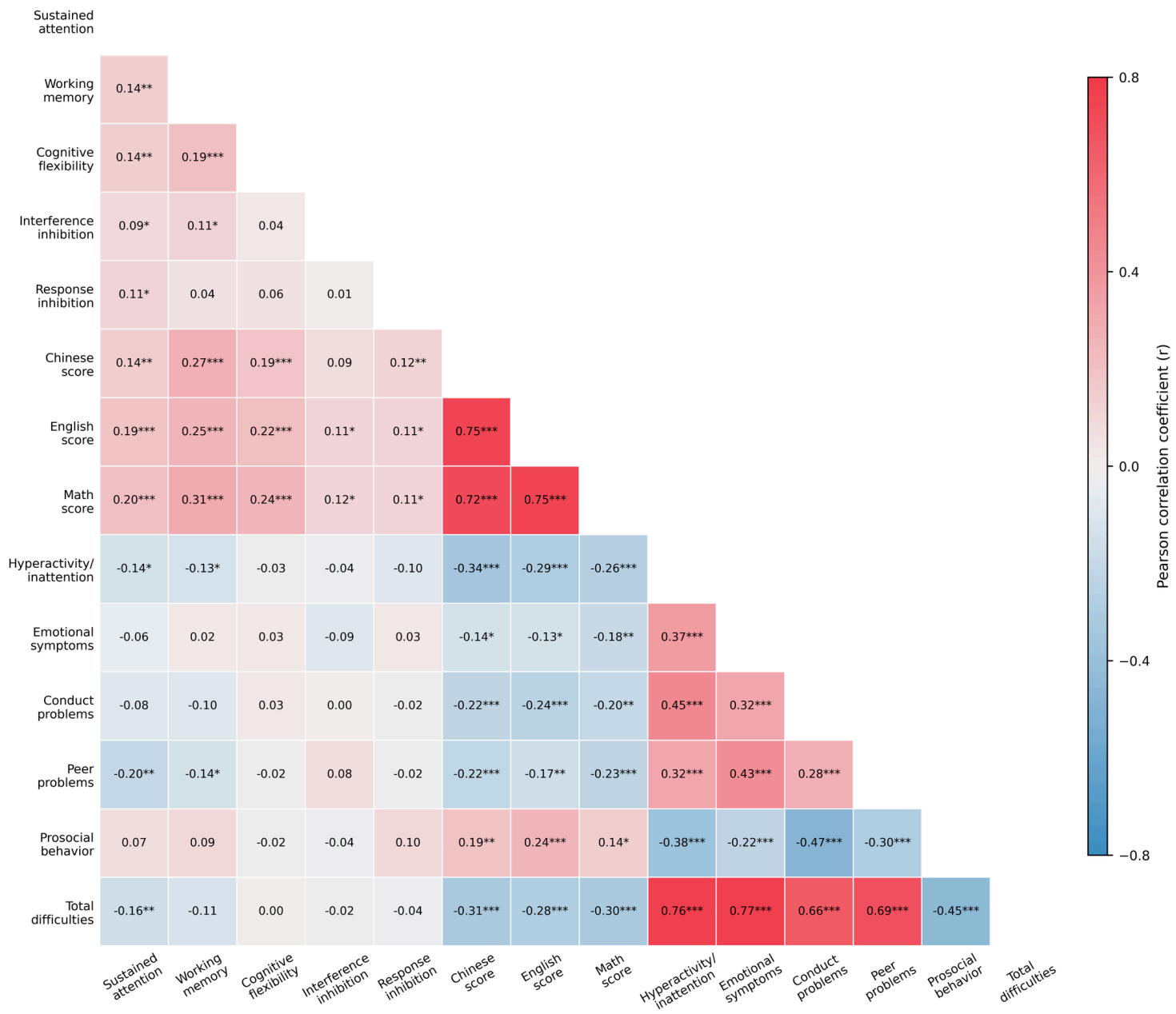


Figure 2

Pearson correlations among study variables. The lower-triangular heatmap displays correlation coefficients among EF tasks, academic achievement, and SDQ measures. Red cells indicate positive correlations, and blue cells indicate negative correlations, with darker colors representing stronger associations. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

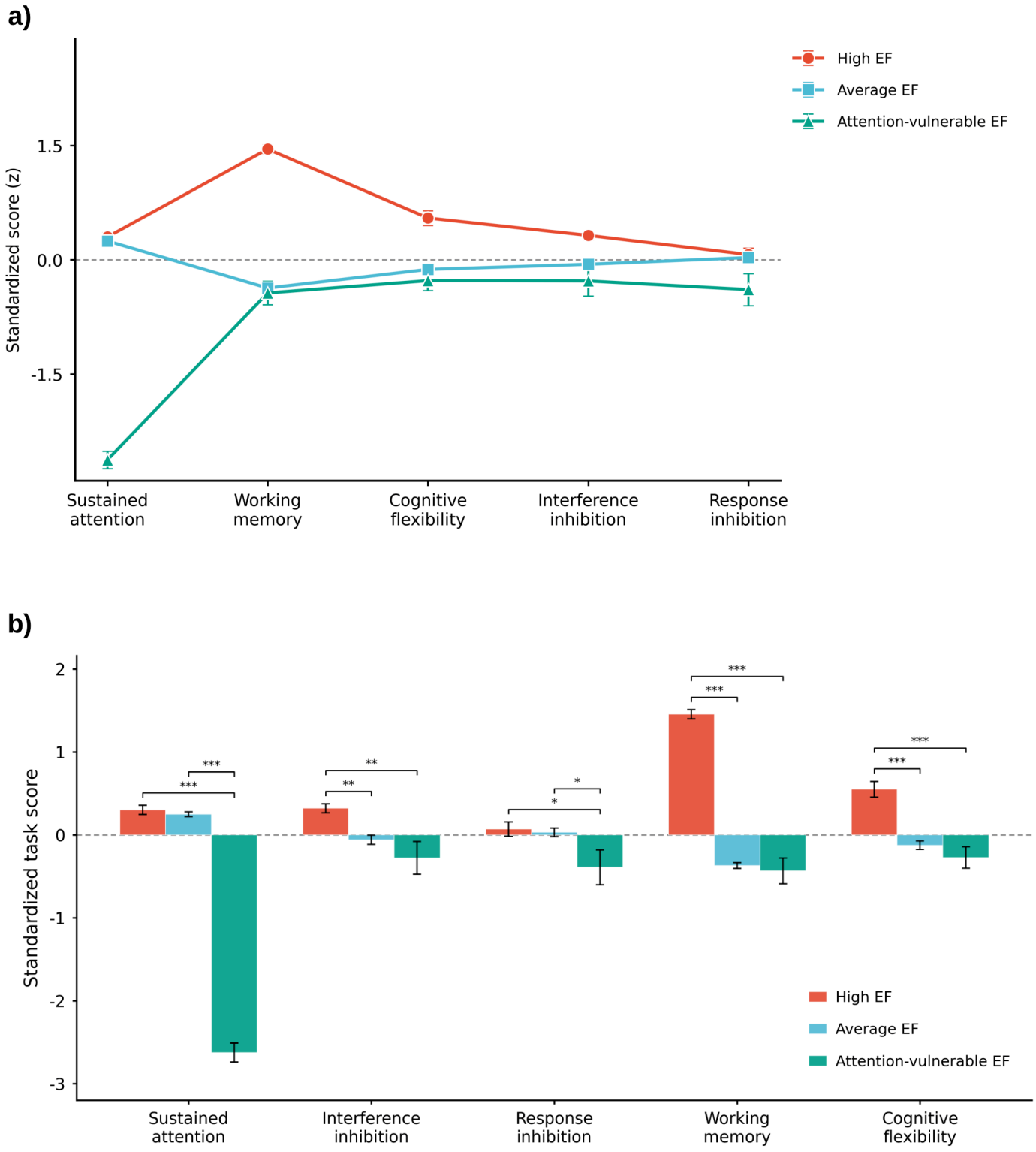


Figure 3

Latent profiles based on standardized EF task scores. a) LPA profiles across the five EF indicators. Points represent standardized profile means, with error bars indicating standard errors. The dashed horizontal line indicates the sample mean (z = 0). b) Mean standardized task scores for each EF indicator across the three latent profiles. Bars represent standardized mean scores, and error bars represent standard errors. Significance brackets indicate Bonferroni-adjusted post hoc comparisons

between profiles. *p< 0.05, **p < 0.01, ***p < 0.001. Higher scores indicate better task performance; Flanker interference and SSRT were reverse-scored.

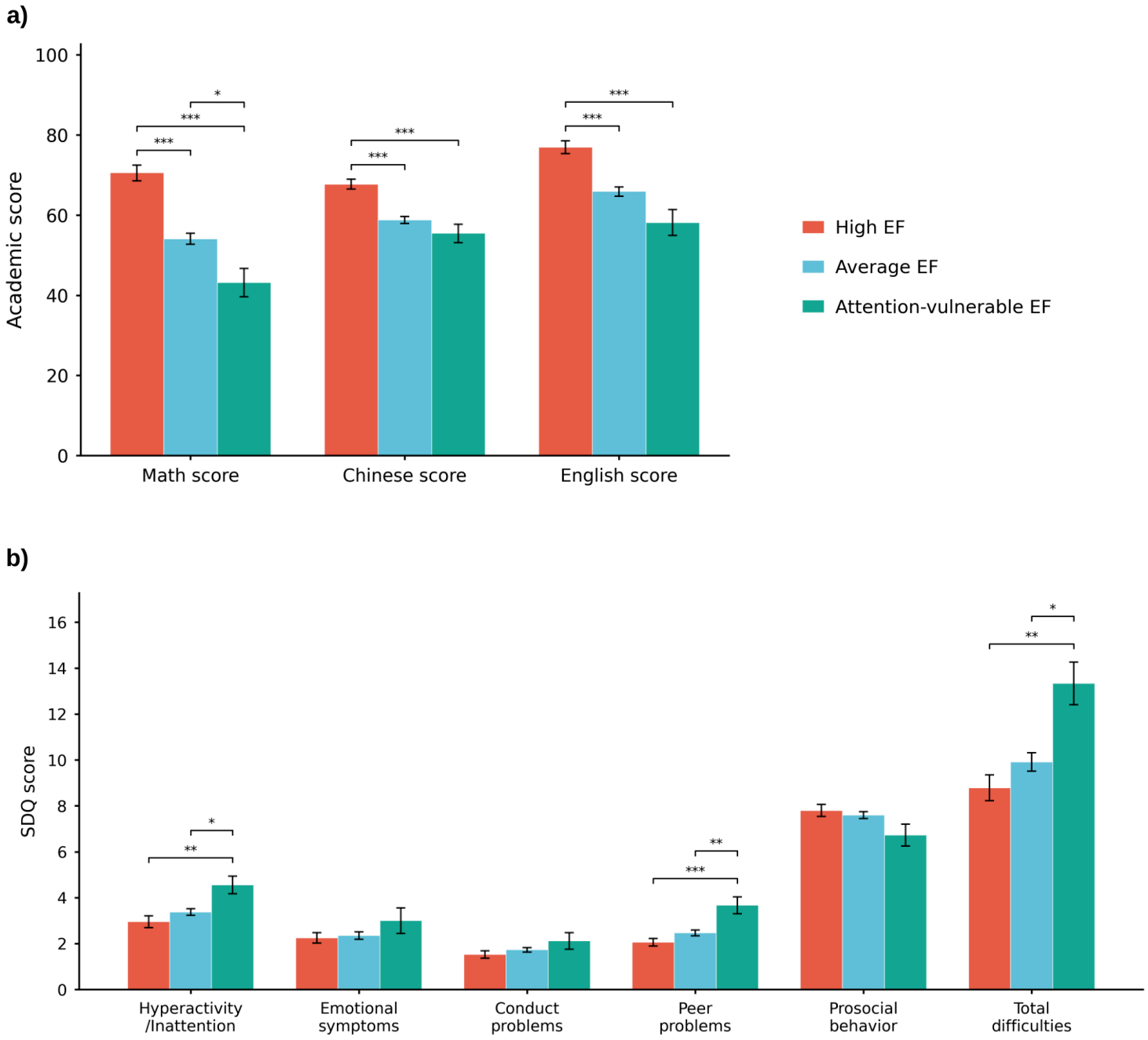


Figure 4

Differences in academic achievement and SDQ scores across EF profiles. a) Academic achievement scores across profiles. **b)** SDQ scores across profiles. Bars represent mean scores, and error bars represent standard errors. Asterisks indicate significant Bonferroni-adjusted post hoc comparisons between profiles. *p < 0.05, **p < 0.01, ***p < 0.001.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryTableS1.docx