The Effect of Central Executive Functions on Writing Ability among Primary School Students in Xinjiang

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Abstract: This study investigates the influence of central executive functions(CEFs) on the writing abilities of fourth-grade students in Xinjiang. The results highlight that the updating function is the most significant component of CEF in improving writing ability. Specifically, updating positively impacts writing fluency, accuracy, and all aspects of teacher evaluations. These findings underscore the importance of incorporating cognitive function assessments into elementary education to identify cognitive developmental delays early and implement timely interventions. Such efforts can effectively reduce the prevalence of writing difficulties.

1. Introduction

Writing is widely regarded as the most challenging language skill for learners to develop to a proficient level[1]. Accordingly, as instructional models and learning-strategy training continue to evolve, a key priority for writing instruction in the national common language and script in Xinjiang is to replace drill-based practices with scientifically grounded and efficient learning and training approaches. With the growing integration of learning sciences and educational neuroscience, central executive function (CEF) has been identified as a critical cognitive determinant of writing acquisition and written production[2]. CEF is the core control component of working memory and comprises three dissociable but moderately correlated processes: updating (monitoring and refreshing information), shifting (switching between tasks or mental sets), and inhibition (suppressing irrelevant information) [3][4]. Functionally, CEF coordinates other working memory subsystems, regulates attentional allocation, and supports goal-directed updating and shifting[5]. Working memory—and CEF in particular—therefore constrains the cognitive processes underlying written production[6]. Accumulating evidence further indicates that delayed or suboptimal CEF development contributes to children's writing difficulties, whereas CEF-targeted interventions can improve writing performance [7]. Fourth grade represents both an early stage in integrating writing-related knowledge and a sensitive period for CEF development[8]. Clarifying how CEF develops during this period and how it shapes writing learning can provide cognitive-neuroscientific guidance for primary-school writing instruction in Xinjiang and inform pedagogical approaches that better align with learners'

developmental trajectories.

Xinjiang is the only provincial-level region in China where ethnic minority populations exceed ten million and constitute more than 50% of the total population[①]. Consequently, its experience in addressing challenges in national common language and script promotion offers valuable insights for nationwide initiatives. However, existing research on children in ethnic minority regions has primarily focused on improving traditional instructional approaches—emphasizing language input and practice—while giving limited attention to the ways in which learners' cognitive resources support language acquisition, processing, and expression. Systematic evidence also remains scarce regarding individual differences in learning capacity, underlying cognitive mechanisms, and feasible intervention pathways. Clarifying the role and mechanisms of cognitive functions, particularly CEF, in the acquisition of the national common language and script could enable more learner-responsive and differentiated instruction in basic education and strengthen foundational language competence in Xinjiang. Against this backdrop, the present study examines fourth-grade students in Xinjiang to assess the specific contribution of CEF to writing production.

2. Study 1: Predictive Effects of CEF on Writing Achievement in the National Common Language and Script among Primary School Students in Xinjiang

2.1 Method

2.1.1 Participants

Using an extreme-groups design, we randomly selected 40 fourth-grade students from the top 27% and 40 from the bottom 27% of the writing-score distribution on the end-of-term Chinese examination (first semester) at a primary school in Xinjiang. These students formed the high- and low-achievement groups, respectively. The high-achievement group had a mean age of 11.00 years ($SD = 0.79$; 22 boys, 18 girls), and the low-achievement group had a mean age of 10.75 years ($SD = 0.64$; 18 boys, 22 girls).Writing scores were significantly higher in the high-achievement group ($M = 62.50$, $SD = 6.29$) than in the low-achievement group ($M = 32.92$, $SD = 10.70$), $t(78) = 10.65$, $p < 0.001$, Cohen's $d = 3.37$, $r = 0.86$.

2.1.2 Measures

(1) Updating task. Updating was assessed using a Chinese-character n-back task [9] with two difficulty levels (0-back and 1-back). Participants indicated whether the current character matched the character presented n trials earlier. Each level included one practice block with feedback. The formal test comprised 32 trials (0-back) and 96 trials (1-back). Accuracy and reaction time were recorded.

(2) Shifting task. Shifting was assessed using a digit–pinyin switching task [9]. Participants made judgments based on the color and content of stimuli presented as digits, pinyin, or digit–pinyin combinations. Three trial types were included: (a) blue digit–pinyin combinations requiring an odd/even judgment for the digit; (b) red digit–pinyin combinations requiring a judgment of whether the pinyin was a simple vowel; and (c) single digits or single pinyin requiring the corresponding judgment. The task included one practice block with feedback and 96 formal trials. Accuracy and reaction time were recorded.

(3) Inhibition task. Inhibition was assessed using a Chinese color–word Stroop task [10]. Depending on task instructions, participants judged either ink color or semantic meaning. Three conditions were

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[①]The data were drawn from the Communique of the Seventh National Population Census and the Main Data of the Seventh National Population Census of the Xinjiang.

included: congruent, incongruent, and neutral (meaningless symbols). The task included one practice block with feedback and 96 formal trials. Accuracy and reaction time in the incongruent condition were used as indices of inhibition.

2.2 Results and Analysis

Data were analyzed in RStudio for Mac (version 4.3.1). For all tasks, accuracy and reaction time (RT) served as outcome measures. All observations fell within ± 3 SDs; therefore, no cases were excluded. As shown in Table 1, the high writing-achievement group exhibited significantly higher accuracy than the low writing-achievement group on the updating, shifting, and inhibition tasks.

Table 1. Differences in accuracy and RT (ms) on CEF tasks between high and low writing-achievement groups ($M \pm SD$).

Task		High	Low	t	Cohen's d	r
Updating	Accuracy	0.71 ±0.19	0.54 ±0.14	3.09**	1.02	0.45
	RT	614 ±155	661 ±182	0.86	0.27	0.14
Shifting	Accuracy	0.46 ±0.20	0.34 ±0.12	2.33*	0.73	0.34
	RT	1735 ±852	1976 ±767	0.94	0.30	0.15
Inhibition	Accuracy	0.81 ±0.16	0.68 ±0.16	2.49*	0.81	0.38

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Same below.

A logistic regression was conducted to predict group membership (high vs. low writing achievement), with accuracy on the updating, shifting, and inhibition tasks entered as candidate predictors using stepwise selection (entry criterion = 0.05). The overall model was significant, $\chi^2 = 8.75$, $p = 0.003$, with -2 log $likelihood$ = 46.70. The Hosmer–Lemeshow test suggested acceptable model fit, $\chi^2 = 8.29$, $p > 0.05$. Classification results indicated that the model correctly identified 55% of students in the high-achievement group and 70% in the low-achievement group, yielding an overall classification accuracy of 62.5%. Of the predictors retained, updating accuracy was a significant predictor of writing achievement ($\beta = 5.77$, $OR = 319.03$, $p = 0.01$).

Collectively, these findings suggest that CEF predicts writing achievement among fourth-grade students in Xinjiang, with predictive sensitivity appearing greater among students with relatively weaker CEF. This pattern is consistent with the view that CEF plays a foundational role in written language production[6]. The results further highlight the prominence of updating: stronger updating ability is associated with better writing performance.

3. Study 2: Effects of Updating on Writing Achievement in the National Common Language and Script among Primary School Students in Xinjiang

Building on Study 1, Study 2 examined how individual differences in updating ability relate to writing achievement among fourth-grade students in ethnic minority regions.

3.1 Method

3.1.1 Participants

Participants were recruited from four primary schools in a region of Xinjiang with comparable instructional capacity and student intakes. In total, 253 fourth-grade students completed the assessment; complete data were obtained from 232 students (response rate = 91.70%). Based on updating-task performance, 40 students were randomly selected from each of the upper, middle, and lower 27% of the score distribution, yielding a final sample of 120 students. The high-updating group had a mean age of 9.93 years ($SD = 0.76$; 15 boys, 25 girls), the medium-updating group had a mean

age of 9.99 years (*SD* = 0.64; 15 boys, 25 girls), and the low-updating group had a mean age of 10.10 years (*SD* = 0.70; 18 boys, 22 girls).

3.1.2 Measures

(1) Updating task. Building on the n-back paradigm used in Study 1, a 2-back condition was added to increase task demands. Each difficulty level included one practice block with feedback. In the formal phase, each level comprised two blocks (150 trials per level), for a total of 450 trials across levels. Accuracy was recorded.

(2) Writing tasks. Participants completed one narrative and one imaginative writing task, with 40 minutes allotted for each essay. The narrative prompt was A Small Incident from My Life, and the imaginative prompt was The Classroom of the Future. Writing performance was evaluated using two scoring approaches: CAF (complexity, accuracy, and fluency) indices and teacher ratings. The CAF scoring rubric is provided in Table 2[11]. Teacher rating criteria were developed in accordance with the Compulsory Education Curriculum Plan and Curriculum Standards (2022 edition) (Table 3), and essays were scored by two primary-school Chinese teachers with more than five years of teaching experience.

Table 2. CAF scoring rubric.

Dimension	Sub-criterion	Operationalization
Fluency	Characters written per unit time	Total characters / writing time
	Words written per unit time	Total words / writing time
Accuracy	Accuracy rate of T-units	Error-free T-units / total T-units
Complexity	Mean length of T-units	Total words / total T-units
	Mean sentence length	Total words / total sentences
	Proportion of complex sentences	Total complex sentences / total sentences

Table 3. Teacher rating rubric.

Category (points)	Sub-criterion	Scoring guidelines
Accumulating materials (15)	Observe the surrounding world and enrich one's experiences	1–5: simple observations; 6–8: habitual observation and description; 9–15: careful observation with distinctive personal insights
Selecting materials (20)	Select materials consistent with writing purpose	1–5: weak relevance; 6–10: relevant materials selected; 11–20: materials selected clearly highlight the purpose
Organizing materials (30)	Clear, orderly expression; cohesion across paragraphs; salient focus	1–8: disorganized, weak cohesion; 9–15: orderly with some cohesion; 16–30: clear and coherent with natural transitions and salient focus
Language use (35)	Use accumulated language resources; clear and fluent sentences; correct punctuation	1–5: simple, monotonous language; 6–8: richer language, fluent, mostly correct punctuation; 9–10: vivid expression, fluent, appropriate punctuation
	Use fresh and appropriate words/phrases; coherent expression; appropriate punctuation	1–5: limited vocabulary, little novelty; 6–8: some novel vocabulary, fluent; 9–10: rich vocabulary, vivid and coherent
	Appropriate word choice; fluent, coherent, vivid expression; accurate punctuation	1–5: inappropriate wording, not vivid; 6–8: relatively appropriate vocabulary and vividness; 9–15: appropriate and rich expression with accurate punctuation

3.2 Results and Analysis

All analyses were performed in RStudio for Mac (version 4.3.1). Updating-task accuracy differed significantly across groups, high ($M \pm SD$ = 0.93 $\pm$ 0.02), medium (0.82 $\pm$ 0.03), and low (0.58 $\pm$ 0.15), $F(1, 118)$ = 259.80, $p < 0.001$, η^2 = 0.69.

CAF indices and teacher ratings by updating group are reported in Table 4. Updating level and genre were entered as independent variables, and separate multivariate analyses of variance (MANOVAs) were conducted for CAF outcomes and teacher ratings. For CAF outcomes, the MANOVA showed a significant main effect of updating level, $F(2, 460)$ = 2.32, p = 0.01, *Pillai's trace* = 0.11. The main effect of genre was not significant, $F(1, 229)$ = 0.78, p = 0.59, *Pillai's trace* = 0.02, and the Updating Level $\times$ Genre interaction was also not significant, $F(2, 460)$ = 0.36, p = 0.98, *Pillai's trace* = 0.02. Post hoc tests indicated that characters written per unit time were higher in the medium group than in the low group (p_{adj} = 0.02) and higher in the high group than in the low group (p_{adj} = 0.02). For T-unit accuracy, the low group scored significantly lower than the high group (p_{adj} = 0.001) and the medium group (p_{adj} = 0.03). No other CAF outcomes differed significantly across groups ($ps_{adj} > 0.05$).

For teacher ratings, the MANOVA revealed a significant main effect of updating level, $F(2, 460)$ = 3.06, p = 0.001, *Pillai's trace* = 0.12. The main effect of genre was not significant, $F(1, 229)$ = 0.41, p = 0.85, *Pillai's trace* = 0.01, and the Updating Level $\times$ Genre interaction was not significant, $F(2, 460)$ = 0.49, p = 0.90, *Pillai's trace* = 0.02. As shown in Table 5, post hoc comparisons further indicated significant group differences for each component of teacher ratings ($ps_{adj} < 0.05$).

Table 4. CAF indices and teacher ratings across updating groups ($M \pm SD$).

Scoring method	Sub-criterion		High		Medium		Low	
			Narrative	Imaginative	Narrative	Imaginative	Narrative	Imaginative
CAF	Fluency	characters per unit time	9.88±4.24	10.30±3.67	8.22±3.73	8.62±3.91	7.78±3.77	9.08±4.16
		words per unit time	2.12±1.49	2.26±1.30	1.90±0.98	2.17±1.43	1.85±1.37	2.02±1.22
	Accuracy	T-unit accuracy	0.61±0.59	0.62±0.59	0.58±0.69	0.54±0.57	0.47±0.55	0.43±0.52
	Complexity	mean T-unit length	0.26±5.09	0.25±5.02	0.27±6.44	0.25±5.66	0.35±6.39	0.32±6.19
		mean sentence length	3.74±7.18	3.00±7.59	3.87±11.10	2.77±11.00	6.15±10.80	4.95±9.31
		proportion of complex sentences	4.55±0.40	4.46±0.40	18.40±0.60	21.30±0.39	9.41±0.53	8.08±0.40
Teacher rating	Accumulating materials		11.00±2.60	11.30±1.99	10.60±2.85	10.30±2.50	9.25±2.21	9.82±2.63
	Selecting materials		14.70±3.28	14.90±2.53	13.70±3.04	13.30±2.71	12.90±2.85	12.80±2.87
	Organizing materials		20.80±5.35	20.90±5.14	19.10±5.59	18.80±5.28	18.40±5.50	18.60±4.75
	Language use		24.30±6.48	25.10±5.54	22.80±6.30	22.60±6.29	21.20±6.30	21.20±5.48
	Total score		70.90±16.80	72.40±14.00	66.20±16.40	65.00±15.60	61.80±15.50	62.50±14.20

Table 5. Post hoc comparisons for teacher ratings.

Outcome	Medium vs. High		Low vs. High		Low vs. Medium	
	95%CI	p_{adj}	95%CI	p_{adj}	95%CI	p_{adj}
Accumulating materials	-1.64, 0.21	0.17	-2.54, -0.70	0.001	-1.83, 0.02	0.06
Selecting materials	-2.39, -0.25	0.01	-3.00, -0.86	0.001	-1.68, 0.46	0.37
Organizing materials	-3.82, 0.09	0.06	-4.30, -0.39	0.01	-2.43, 1.48	0.83
Language use	-4.27, 0.24	0.09	-5.79, -1.28	0.001	-3.77, 0.74	0.26
Total score	-11.74, -0.29	0.04	-15.20, -3.74	0.001	-9.18, 2.27	0.33

Overall, these results suggest that students with stronger updating ability produce written texts

characterized by greater fluency and accuracy. These students also receive higher teacher ratings, indicating that updating supports real-time information maintenance and monitoring during writing.

4. Discussion

Writing is a high-level, integrative language activity that draws heavily on cognitive resources, particularly working memory, to coordinate processing across multiple linguistic levels (e.g., characters/words, sentences/paragraphs, discourse organization, and grammar). The present study indicates that CEF—especially updating—predicts writing achievement among primary school students in ethnic minority regions and is associated with the quality of written output. In the early and less proficient stages of writing development, learners are more likely to be constrained by working memory and executive control. Sustained high cognitive load may compromise updating, weakening the ongoing regulation and monitoring of working-memory contents and thereby increasing errors during writing. Learners with higher working memory capacity can allocate resources more efficiently, integrate meaning and form, and engage in iterative planning and revision, which may facilitate progression to more advanced stages of writing[12]. By contrast, learners with lower working-memory capacity may rely primarily on partial, lower-level data-driven processing, limiting their ability to integrate and apply previously acquired knowledge, experience, and strategies; this constraint is likely to undermine text quality and impede writing development.

These findings underscore the instructional value of assessing students' cognitive developmental profiles alongside writing instruction. Regular screening, the establishment of individual cognitive function profiles, and proactive monitoring may strengthen early identification of cognition-related writing difficulties in ethnic minority regions. Such practices may also benefit typically developing students, for whom writing can impose substantial cognitive load; sustained high load can reduce working-memory efficiency and compromise writing outcomes. When teachers understand students' cognitive profiles and adjust task demands and instructional supports accordingly, writing learning may be eased and instructional benefits maximized.

Evidence further suggests that CEFs can be enhanced through interventions such as adaptive cognitive training, neurofeedback, and transcranial magnetic stimulation (TMS) [13][14]. As these approaches have been increasingly applied in educational research, growing evidence indicates that cognitive interventions may yield positive far-transfer effects on writing achievement[7]. Accordingly, schools could use cognitive-assessment results to establish school–medical collaboration mechanisms and provide timely, targeted interventions for children who show weaknesses in CEF, thereby mitigating early writing difficulties associated with atypical cognitive development.

Given the foundational role of working memory in academic learning, cognitive load theory emphasizes optimizing instructional design to reduce extraneous load and improve learning efficiency [15]. However, implementation in educational settings has been limited, in part because many educators lack formal training and applied experience in cognitive science. Insights from educational neuroscience further suggest that factors frequently emphasized in educational practice—such as motivation, emotional arousal, and physical activity—can modulate cognitive functioning[16]. Clarifying and leveraging these interrelations may reduce teachers' burden of acquiring extensive extra-disciplinary expertise and provide a learner-centered, supportive framework for writing instruction in ethnic minority regions.

5. Conclusion

The present study shows that CEF predicts writing achievement among fourth-grade students in Xinjiang, with particularly strong associations among students with lower writing performance. Updating, in particular, was positively associated with writing fluency and accuracy as well as teacher

ratings.

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