READING PSYCHOLOGY
https://doi.org/10.1080/02702711.2025.2566026

Routledge
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The Mediating Role of Executive Functions in Reading Fluency Among 8-10 Year Old Children: Evidence from a Transparent Orthography

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ABSTRACT

The authors investigated the contribution of executive functions (EFs) in mediating the relation between age and reading fluency (RF) in school children. A total of 168 typically developing 8-year-old children (M age = 8 years, 4 months) and 10-year-old children (M age = 10 years, 3 months) were assessed with an RF task, isolated measures of EFs, a collective measure of EFs, and a non-verbal intelligence test. The results showed that during both age periods, inhibition, updating and cognitive flexibility were significant predictors of RF, explaining 23% of its variance. The results also revealed a significant partial indirect effect of age on reading fluency through all three hypothesized mediators supporting the mediating hypothesis. These findings further support the differentiation of EFs into distinct components for these particular age groups. A novelty of this study was that it provided evidence of this mediating relationship from a highly transparent orthography, that of the Albanian language. Neither gender nor non-verbal intelligence made any difference. However, two demographic variables, namely Socio-economic status (SES) and the mother education level, significantly moderated the relationship between age and RF.

ARTICLE HISTORY
Received 24 June 2025
Accepted 22 September 2025

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Introduction

Reading is a complex task, which requires the coordination of a myriad of cognitive skills and abilities (Oakhill et al., 2014). According to the Simple View of Reading (SVR), it relies on two core components: word recognition and language comprehension (Hoover & Gough, 1990). Within this view, the language comprehension refers to interpreting oral discourse (Hoover & Gough, 1990) while the word recognition component refers to recognizing words fast and effortlessly (Sánchez-Vincitore et al., 2022). The automaticity in word recognition is explained by the dual-route model, which describes two separate cognitive pathways engaged during the reading process (Coltheart & Rastle, 1994). The non-lexical route involves a conversion of printed words into phonological representations letter-by-letter through a grapheme-to-phoneme correspondence rules and is critical for early readers (Knoepke et al., 2014). In contrast, the lexical route becomes more prominent as reading experience increases. This pathway allows readers to instantly recognize familiar words as whole units, offering a faster and more efficient mechanism for reading (Knoepke et al., 2014). Using one route or the other depends on different factors such as word frequency, reading experience, and orthographic transparency (Sánchez-Vincitore et al., 2022).

This study will focus specifically on the lexical recognition component of the SVR, examining the speed of reading or reading fluency, as it serves as a critical foundation for effective word recognition and overall reading comprehension in children. Reading fluency is a highly relevant and transferable skill in young children (Henry et al., 2015). Fluency is also a key element of oral reading performance, a significant indicator of overall reading competence (Fuchs et al., 2001). Efficient and accurate word reading frees up more cognitive space in working memory, allowing it to be used for meaning construction (Chang, 2020; Perfetti, 2007; Wolf & Katzir-Cohen, 2001). Thus, greater fluency allows a child to read more efficiently, dedicating fewer cognitive resources to basic reading processes and enabling more focus on higher-order aspects of reading.

Reading Fluency

Reading fluency increases with age in typically developing children (Hurks et al., 2010; Kavé, 2006; Kavé et al., 2008; Sauzéon et al., 2004). The more children are exposed to words reading, the faster and more accurate they become in their reading skills. In general, fluent reading develops in most children between first and third grade, when their decoding skills are improved through practice (Kuhn & Stahl, 2003). However, findings from brain studies indicate that a gradual specialization of word recognition process continues to develop for years (Brem et al., 2006; Posner & McCandliss, 1999; Schlaggar & McCandliss, 2007). The most common way of assessing reading fluency in children is with tasks involving isolated words, where children are required to read each word as quickly as possible within a 1-minute time frame (Nguyen et al., 2020; Ripoll Salceda et al., 2014). To produce words accurately, information retrieved from the mental lexicon must be organized effectively (John & Rajashekhar, 2014). This process demonstrates both the accuracy and fluency of spoken words, making it an essential skill for language production and general academic success (Memisevic & Djordjevic, 2018).

Interaction of Orthographic Depth and Reading Fluency

The degree of orthographic transparency plays a role in determining how the word recognition component of the SVR theory contributes to reading (Catts, 2018). In languages with a transparent orthography (e.g., Italian, Finnish, Albanian), children rely mostly on the non-lexical route, due to a highly consistent mapping between graphemes and phonemes. Conversely, in languages with an opaque orthography, written words are converted to sounds mainly via the lexical route (Frith et al., 1998; Ziegler et al., 2010). That is because in opaque orthographies (e.g., English, French, Danish), graphemes do not always correspond to a single phoneme, and so using the non-lexical route may result in incorrect phonological representations of a written word (Borleffs et al., 2017). As a result of this fundamental difference between transparent and opaque orthographies, the ability to read words fluently may well differ across orthographies. Several studies have reported that reading fluency develops earlier in more transparent languages than in more opaque languages (Ellis et al., 2004; Florit & Cain, 2011; Seymour et al., 2003; Ziegler & Goswami, 2005). However, there still remain unanswered questions regarding the development of reading fluency in different languages, especially those that are highly transparent orthographies.

A good example of a language with a highly transparent orthography, is the Albanian language. Albanian-speaking children develop their reading fluency skill in the first years of education (6 to 7 years of age) (Ellis et al., 2004). In a study comparing Albanian language with Welsh as a relatively transparent language and English as a highly orthographically opaque language, it was observed that 7-year-old Albanian-speaking children became more skilled in RF and accuracy earlier than Welsh- and English-speaking children (Hoxhallari et al., 2004, 2006). To our knowledge, no other studies examining the development of reading fluency, and the cognitive processes involved thereon, were conducted with children of the Albanian language. Considering the highly regular mapping between the graphemes and phonemes of the Albanian language, examining these important processes in young children of this orthographically transparent language would provide important insights in this perspective. Therefore, investigating the development of reading fluency among Albanian-speaking children could offer valuable insights into the current understanding of how reading fluency differs across languages.

Contribution of EFs to Reading Fluency

In their efforts to produce speech accurately and efficiently, children rely on a range of domain-general cognitive skills (Horowitz-Kraus & Finucane, 2016; Ruffini et al., 2024). Among them, the most important are a group of cognitive skills known collectively as executive functions, as defined by Miyake's three-factor model (Miyake et al., 2000). Executive functions (EFs) are a set of cognitive control processes that modulate the dynamics of human cognition (Miyake et al., 2000). These fundamental skills are vital for everyday goal-directed behavior throughout the lifespan and have been shown to predict academic success from childhood onward (Schirmbeck et al., 2021). Inhibition refers to the capacity to suppress automatic responses (response inhibition) or to ignore distracting stimuli (interference control). Updating involves the ability to briefly store and continually revise information with newly coming information. Cognitive flexibility (CF) is the ability to adjust thoughts and behaviors in response to changing goals, rules, or environmental demands. Collectively, these EF components are engaged when one must retain and update information, filter out irrelevant data, and shift between different aspects of a task in real time. Therefore, it is plausible to suggest that their role in a reading fluency task for children would be to allow them to read accurately but also quickly (Biscevic et al., 2018; Jacobson et al., 2017; Ruffini et al., 2024).

EFs are known to involve both shared and distinct cognitive components simultaneously (Miyake et al., 2000; Miyake & Friedman, 2012). That is, various EF's measures reflect both a shared underlying ability and separate, specific components. According to Miyake et al. (2000), cognitive flexibility, updating, and inhibitory control are moderately related, but clearly separable, in undergraduate students. However, studies with young children have shown that they are a unitary construct (e.g., Wiebe et al., 2008). More recently, Miyake and Friedman (2012) argued that the shared part of executive functions is most strongly found in clinical samples. Taking into account the complexity of EFs, it would be valuable to examine EFs both with isolated tasks and with a single, collective EFs task, to understand whether unity or diversity of EFs is present in typically developed children. For example one of the tasks that is considered to measure all EFs collectively is the Trail Making Test (Lezak, 1995; Mitrushina et al., 2005; Strauss et al., 2006), especially part B of the task was found to involve executive functions (Sánchez-Cubillo et al., 2009). Thus in an attempt to understand their shared involvement or separate involvement in domain-specific skills such as reading fluency, it would be useful to use both isolated EFs tasks and a TMT task.

Relationship Between EFs and Reading Fluency

Due to the importance of understanding the role that domain-general cognitive skills play in reading fluency, several studies have examined the relationship between reading fluency and executive functions (EFs). For example, in a study by Kieffer and Christodoulou (2020), it was found that children of the 7th grade with better executive functions as compared to those with weaker executive functions, had higher reading fluency levels (Kieffer & Christodoulou, 2020). Similarly, Arrington et al. (2014) found working memory and response inhibition to be direct and significant predictors of word-reading efficiency by analyzing data from children in grades 6–12. Also, Jacobson et al. (2017) found cognitive flexibility to significantly predict reading fluency in a sample of children aged between 8 and 15 years of age which authors attributed to the nature of timed tasks; given that attentional switching was measured on a timed task as well as fluency. However, the majority of these studies have examined this relationship by considering reading fluency as a mediator in the relationship between EFs and reading comprehension. Other studies have mainly tested the importance of EFs in reading comprehension (Cutting et al., 2009; Sesma et al., 2009), but very few have tested the role of EFs in RF (Miller et al., 2014; Nguyen et al., 2020; Spencer and Petersen, 2018). Thus, despite strong interest in EFs and reading fluency in an indirect route, a closer relation between the two has rarely been examined (Kieffer & Christodoulou, 2020). Given the evidence that both EFs and reading fluency predict reading comprehension, it is essential to deepen our understanding of the relationship between EFs and reading fluency, by looking at other routes and factors such as age, SES and the interactive role of orthography.

This study aims to examine the contributing role of age and EFs to reading fluency in a transparent orthography. This is mainly due to the important variations in reading fluency development in different orthographies, with earlier development of reading fluency skill occurring in more transparent orthography. The deeper the orthography, the greater the demands placed on EFs (Filipe et al., 2025). Understanding how EFs contribute to reading fluency in a highly transparent orthography is highly valuable.

Existing Research Gaps

The existing studies have several limitations. First, very few studies have examined the relationship between EFs and reading fluency, with reading fluency as a primary outcome variable. The majority of studies have looked at this relationship to understand their prediction to reading comprehension, with reading fluency as a mediator only. Since both EFs and reading fluency have been shown to significantly predict reading comprehension in children, their interaction warrants further investigation (Kieffer & Christodoulou, 2020). Second, most studies focus on opaque orthography, leaving a gap in understanding how reading fluency is predicted by age and how EFs relate to reading fluency in more transparent orthographies (Berninger et al., 2008). Moreover, the language examined in this study, the Albanian language, is an understudied language and as such could reveal important insights in this aspect. Third, research frequently examines EFs and reading fluency in clinical samples leaving unanswered questions as to how the core EFs are interrelated or separated in typically developing school children.

Aims of the Study

The present study was undertaken to examine developmental trends in reading fluency within a group of typically developing Albanian-speaking children of 8 and 10-years of age. Given that performances in the EF tasks are highly correlated among the preschool children (Marzocchi & Mingozzi, 2022; Ruffini et al., 2024), we would like to test if such correlation holds among the more mature schoolchildren aged 8–10. This is in line with the hypothesis of a progressive differentiation during development of the EFs. There are studies on children that suggest that EF basic components may play a different role in supporting reading fluency (Ruffini et al., 2024). More specifically, the present study aimed to examine whether:

1. Basic executive function (EF) components in 8 and 10 year-old children predicted a significant portion of the variance in reading fluency, and which EF component had the greatest influence;
2. EFs mediated the effect of age on performance in the reading fluency task.

Main hypothesis:

- H1: Age predicts reading fluency in such a way that as age increases, the performance in reading fluency improves.
- H2: All three core executive functions directly, and indirectly through age, predict reading fluency performance.
- H3: EFs are distinct constructs among the school children, with each sub-component having a unique role in reading fluency.

Method

A total of 168 children participated in this study (M = 9 years, 10 months; range = 8 years, 2 months to 10 years, 5 months). Participants were recruited through word of mouth from three public primary schools and one private school in Prishtina, Kosovo. Given that 93% of Kosovar population are Albanians, Albanian language is the dominant language in Kosovo (Canaj, 2020). Children were excluded if they had been placed in special education classes, had a diagnosed learning disability, or did not speak Albanian as their first language. Additionally, bilingual children were excluded from the study, as previous research has suggested that bilingual children tend to have better executive functions than monolingual children (Bialystok, 1999). The study received approval from both the University of Sheffield's Department of Psychology Ethics Committee and the Ministry of Education, Science and Technology of Kosovo. Parents of the children were informed about the study and asked for their consent for their child's participation. Additionally, all participating children were informed that they could withdraw from the study at any time if they chose to do so.

Tasks were administered across two sessions, each lasting around 45 minutes. The first session comprised the Reading Fluency task, the N-back task, and the Raven's Colored Progressive Matrices test. The second session comprised the Eriksen Flanker task, the SwIFT task, and the TMT task. Children were tested individually in their schools. The tasks were presented in a pseudorandom order.

Material

Reading fluency

Reading fluency skills were measured with a task that required children to spend 60 seconds reading a list of 100 words, as quickly and accurately as they could. Each word in the task appeared one at a time on a PowerPoint slide. In the practice phase, children read a 20-word list in the same font as the main task and were instructed to read quickly and accurately. In the testing phase, they read a sequence of increasingly difficult words: 51 short (under four letters) and 49 long (five letters or more), ordered by decreasing frequency (see Hoxhallari, 2006).

Non-verbal intelligence

The Raven's Colored Progressive Matrices Test was used to assess children's non-verbal intelligence and it lasted 10 minutes. In this task, children were presented with 36 trials, each featuring a series of abstract shapes that formed a logical pattern, with one image missing. Children were required to identify which of the six possible response options completed the pattern.

Updating

An experimental N-back Task was used to assess children's updating skills and lasted approximately 15 minutes. In the task, children were shown a series of numbers, presented one at a time. Each time a new number appeared, children had to determine whether it matched the number presented two steps earlier. They were told to press a key if the number on the screen was the same as the one shown two steps before, and to refrain from responding if the number differed from the one presented two steps earlier.

Inhibition

Eriksen Flanker Task was used to assess children's inhibition to suppress irrelevant information and lasted 15 minutes. In this task, children were shown a row of five stimuli and were required to respond based solely on the central stimulus, meaning they needed to ignore the surrounding flanker stimuli. The target stimulus was a letter (either A or M), and the stimuli remained on the screen until the children made a response. The task included three types of trials, differing based on the nature of the flanker: neutral trials, compatible trials, and incompatible trials. In all conditions, the target letter was flanked by two distractors on each side. The flanker stimuli could be: (a) asterisks (neutral trial), (b) matching letters (compatible trial), or (c) different letters (incompatible trial).

Cognitive flexibility

Switching, Inhibition, and Flexibility Task (SwIFT) was used to assess children's CF's and lasted 15 minutes. In the task, children were presented with two colorful shapes and instructed to select the one that matched a third colorful shape, based on either its color or shape. The task began with two "pure" blocks, where stimuli were sorted using only one rule (either Shape or Color, in alternating order). In the third "mixed" block, stimuli were sorted based on both rules—Shape and Color—with the rule to be applied changing pseudorandomly. (Schwanenflugel et al., 2004).

Collective assessment of EFs

Trail Making Test (TMT) (Reitan & Wolfson, 1995) was used to assess EFs collectively and lasted 10 minutes (e.g., Sánchez-Cubillo et al., 2009). The task was composed of two conditions, in the first condition the children had to connect numbers from 1 to 25, and in the second condition they had to connect numbers and letters in a sequence (i.e., 1, A, 2, B, 3, C, etc.). The dependent variable was the time taken to perform this second condition after considering the time taken to complete the previous condition in the test (which consisted solely of connecting the numbers).

Results

The results are presented in five sections: a) descriptive statistics, b) correlational analyses, c) *t*-test between age groups, d) multiple regression analyses; e) mediation/moderation analysis. Prior to results the data were processed for quality check and outlier identification across all measures. A few bivariate outliers were detected and removed from the sample based on Cook's Distance. Exploratory data analysis using a Shapiro-Wilk test showed that the normality assumption is not violated for the outcome variable of reading fluency (RF), $W(168)=.989$, $p=.188$. In addition, Q-Q plots for reading fluency measures were examined. Q-Q plots are used to assess deviations from a normal distribution (Harpe, 2015). The plots showed that the data for the outcome variable were normally distributed. Descriptive statistics for the sample demographics are presented in Table 1.

Table 1. Descriptive statistics for the sample demographics.

	N	Percentage
Gender	168	Male (43.5)
		Female (56.5)
Socio-economic status	168	Low (25.0)
		Middle (23.8)
		Upper (51.2)
Mother's education	168	Junior High school (11.3)
		High school (44.6)
		Technical school (11.3)
		Higher education (32.7)
Father's education	168	Junior High school (2.4)
		High school (47.0)
		Technical school (10.7)
		Higher education (39.9)

Descriptive statistics for the key variables are presented in Table 2. The skewness values are mostly symmetrical (range −0.5 and 0.5), with the exception of FC that is negatively skewed. Most Kurtosis values fit within the range of minus 2 and 2. There is higher value Kurtosis for FC, meaning that the answers are centered around the mean. Analysis of multicollinearity ensured that there are no variance inflation factors (VIF).

Results of the bivariate correlational analysis (see Table 3) show that scores on the RF task significantly and positively correlated with age, non-verbal intelligence, all EF measures, and a collective measure of EFs (i.e. Trail Making Task, TMT), which is negatively correlated, as expected. It is worth noting that relatively strong correlation is observed between updating and non-verbal intelligence, while lower and even nonsignificant correlations are observed between EFs measures. These weak associations across the EFs measures calls for examination of each of the executive functions individually as a potential predictor of reading fluency.

Table 2. Descriptive statistics for the key variables.

							Collinearity statistics	
Measures	*N*	Mean (SD)	Min	Max	Skew	Kurtosis	Tolerance	VIF
Reading Fluency (RF)*	168	65.14 (7.48)	45	87	.304	.309	–	–
Collective EFs (TMT)*	168	40.51 (11.53)	18	74	.451	−.231	.678	1.475
Updating (NBackTC)*	168	45.09 (5.25)	29	59	−.215	−.079	.621	1.611
Inhibition (FC)*	168	88.68 (6.48)	54	100	−1.757	5.011	.664	1.505
Cognitive Flexibility (SA)*	168	12.48 (1.85)	7	17	−.416	−.130	.890	1.124
Age (months)	168	119.65(13.85)	95	145	−.004	−1.533	.731	1.369
Non-verbal Intelligence (Raven's test)	168	30.93 (2.51)	24	36	−.243	−.351	.760	1.317

Note: *RF = Words read within the first 1 min; TMT = time taken to connect letters and numbers in sequencing order; NBackTC = correctly identified target; FC = correctly identified targets in the compatible condition; SA = total accuracy score in the Swift Task.

Table 3. Correlations between RF, EFs measures, non-verbal intelligence and age.

	Measures	1	2	3	4	5	6	7
1.	Reading Fluency (RF)	–						
2.	Collective EFs (TMT)	−.32**	–					
3.	Updating (NBackTC)	.35**	−.27**	–				
4.	Inhibition (FC)	.18*	−.03	.08	–			
5.	Cognitive Flexibility (SA)	.23**	−.04	.21**	.10	–		
6.	Non-verbal Intelligence (Raven's test)	.15*	−23**	.37**	.02	−.00	–	
7.	Age (months)	.38**	−.37**	.29**	.14	.18*	.25**	–

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

There was a significant difference in the RF performance scores between age group (8 years old) (M = 61.7, SD = 6.83) and age group (10 years old) (M = 67.3, SD = 5.63), *t*=(166)=-5.771, *p*=.000, confirming the main hypothesis H1. Thus, as hypothesized, age had a positive effect on reading fluency. Yet, from a theory standpoint, the more interesting probe is whether the EFs measures predict reading fluency beyond the confounds, and whether there are significant indirect effects. In other words, the relationship between age and reading fluency should be moderated and/or mediated by those constructs (see Table 4).

Multiple regression analyses was conducted to investigate the predictive role of the different EF measures evaluated in this study in reading fluency. Data were first screened to make sure they meet the criteria for using parametric tests. Linearity and homoscedasticity were assessed by a plot of standardized residuals against the predicted values. The availability of multiple predictors in the same analysis allows unique (or direct) and shared (or indirect) relations to be distinguished. Multiple linear regression analysis confirmed that EF measures evaluated in this study explained 20% (Adjusted R Square) of the RF performance variability ($F(4, 163) = 11.41$, $p < .001$) and that all EF measures were significant predictors (including the Inhibition indicated as borderline significant at 0.05 probability level) (see Table 5).

Squared semipartial correlations (sr^2) for each of the significant predictors were then calculated to examine the unique variance predicted by each independent variable after intercorrelations between the other independent variables in the regression had been taken into account. This analysis revealed that Updating and TMT as a collective measure of EFs

Table 4. Independent samples *t*-test for reading fluency scores.

	Age group (8 years old) *n* = 79		Age group (10 years old) *n* = 89				
Variables	M	SD	M	SD	*t*	*p*	Cohen's d
Reading Fluency	61.7	6.83	67.3	5.63	−5.771	.000**	0.89

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

Table 5. Regression coefficients of the EF predictors on the RF task.

	B	SEB	ß	*p*	sr^2
Constant	36.840	8.104		.000	
Collective EFs (TMT)	−.143	.042	−.243	.001	.05
Updating (NBackTC)	.304	.095	.235	.002	.05
Inhibition (FC)	.143	.073	.137	.052	.02
Cognitive Flexibility (SA)	.579	.261	.158	.028	.02

Note: sr^2 = squared semipartial correlation, Dependent variable: Reading Fluency (RF).
Independent Variables: Collective EFs (TMT), Updating (NBackTC), Inhibition (FC), Cognitive Flexibility (SA).

accounted for 5% of unique variance each, while other EFs tasks accounted for less, namely, 2% accounted for by the Inhibition and Cognitive flexibility tasks each, respectively.

After controlling for age, gender, non-verbal intelligence (Raven's test), and the socio-economic status, the model remained significant, explaining 23% (Adjusted R Square) of the RF performance variability ($F(8, 159) = 7.06$, $p < .001$), with Updating and TMT remaining significant predictors, $p < .05$, while inhibition and cognitive flexibility losing significance for two-tailed test at p=.09, remaining significant for one-tail test, p<.05. Bar age (B=.110, p=.004), none of the other demographic variables were significant predictors of reading fluency in the final model: gender (B=.917, p=.334), socio-economic status (B=.043, p=.655), non-verbal intelligence (B=-.095, p=.658). Residuals met the assumption of independence (Durbin-Watson statistic = 1.54).

Serial Mediation Model

In the analysis of the serial mediation model, the EFs significant predictors were considered as possible mediators in the relationship between age and RF (Model 6, Hayes, 2022). The results showed that age predicted both directly (t = 3.09, p< .001, e = .11, se = .04) and indirectly (Figure 1), the performances on the RF task ($F(4, 163) = 13.19$, p< .001, R square =.24, MSE = 35.74). The impact of age on all three hypothesized mediators was found significant.

Six permutations of mediator ordering in the mediation model were tested, all confirming the same strength of the indirect effect of age on reading fluency through the tested mediators (Table A1). However, the order reported (Figure 1) has accounted for a maximized number of significant indirect effect pathways, due to a full mediation relationship revealed between cognitive flexibility (SA) and collective measure of EFs (TMT) through updating (NBackTC) (Table A2). This is the case of statistically significant indirect effects in the absence of a total effect due to mediating paths that cancel each other out (Figure A1).

To test for any potential moderation Hayes process macro (Hayes, 2022) was utilized. To avoid potentially problematic high multicollinearity with the interaction term, the variables were centered and the interaction terms between age and the respective hypothesized moderators were automatically created. No moderation effect was found for Intelligence (Raven's test) in the relationship between age and reading fluency (b=.0009, t=.0128, p=.9898, R Square change = .0000). Likewise, no moderation effect was found for gender in the relationship between age and reading fluency (b=-.0162, t=-.2290, p=.8192, R Square change = .0003).

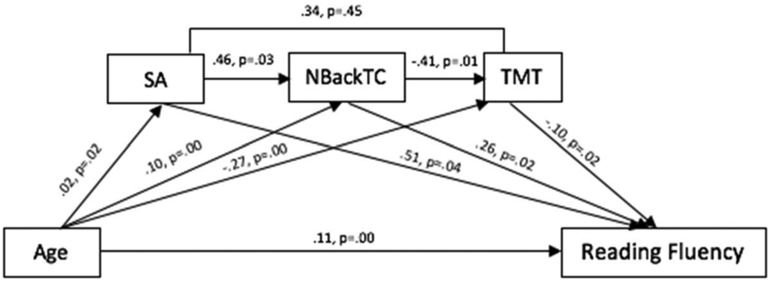

Figure 1. Serial Model of the EF mediation on the relationship between age and the performances on the RF task.
Indirect effect key:
Ind1 Age -> SA -> RF (e=.0123, se=.0085, Boot LLCI= −.0005, Boot ULCI=.0324).
Ind2 Age -> NBackTC -> RF (e=.0260, se=.0119, Boot LLCI=.0067, Boot ULCI=.0527).
Ind3 Age -> TMT -> RF (e=.0271, se=.0162, Boot LLCI=.0003, Boot ULCI=.0630).
Ind4 Age -> SA-> NBackTC -> RF (e=.0029, se=.0022, Boot LLCI=.0001, Boot ULCI=.0085).
Ind5 Age -> SA -> TMT -> RF (e= −.0008, se=.0014, Boot LLCI=-.0042, Boot ULCI=.0015).
Ind6 Age -> SA -> TMT -> RF (e=.0041, se=.0031, Boot LLCI=-.0002, Boot ULCI=.0115).
Ind7 Age -> SA -> NBackTC->TMT -> RF(e=.0005, se=.0005, Boot LLCI=.0000, Boot ULCI=.0017).

The results revealed a significantly negative moderating role of socio-economic status (SES) on the linkage between age and reading fluency (b=-.0164, t=-2.5233, p<.05). Furthermore, the graph shows a steeper gradient for low and average SES (Figure A2). The impact of age on reading fluency is much stronger at low and average levels of SES. Hence, higher SES weakens the impact of age on verbal fluency. According to Johnson-Neyman significance regions for moderator values, after a certain value of SES (6.3109) the SES ceases to moderate the relationship between age and reading fluency (Tables A3 and A4).

The results revealed a significantly negative moderating role of Mother's educational level on the linkage between age and verbal fluency (b=-.0730, t=-2.1177, p < .05). The graph shows a steeper gradient for low and average Mother's educational level (Figure A3). The impact of age on reading fluency is much stronger at low and average levels of Mother's educational level. According to Johnson-Neyman significance regions for moderator values, after a certain value of Mother's educational level (1.1710), the Mother's educational level ceases to significantly moderate the relationship between age and reading fluency. No moderation effect was found for Father's education level in the relationship between age and reading fluency (b=-.0485, t=-1.3202, p=.1886, R Square change = .0089).

Discussion

The present study investigated the relationship between performance in a reading fluency task and the basic components of Executive Functions

(EFs) in 8 and 10-year-old children. The key hypothesis was that reading fluency (RF) increases with age, along with the maturity of executive functions. Another hypothesis was that the basic executive function (EF) components in 8 and 10 year-old children predicted a significant portion of the variance in reading fluency, by mediating the relation between age and reading fluency. Importantly, the context for this study was to look at reading fluency in a language with a highly transparent orthography (specifically, the Albanian language), and at a crucial time in development—the point at which children are becoming fully independent readers (i.e. 8 and 10 year-old children).

The first finding of this study is that in 8 and 10-year-old children, reading fluency is significantly underpinned by all basic EF components (i.e., updating, inhibition, and cognitive flexibility). Multiple linear regression analysis confirmed that EF measures evaluated in this study explained 20% (Adjusted R Square) of the RF performance variability (F(4, 163) = 11.41, $p < .001$) and that all EF measures were significant predictors. After controlling for age, gender, non-verbal intelligence, and socio-economic status, EF's explained 23% of the performance in the reading fluency task. This finding supports our hypothesis, which proposed that all three core executive functions directly predict reading fluency, but also mediate the relationship between age and reading fluency performance. The results are also in line with a study involving a huge sample of children of 3rd, 4th and 5th grade conducted by Cirino et al. (2019) and minority children between 8 and 15 years of age in a study by Jacobson et al. (2017). Thus it is plausible to suggest that, beyond automatized word recognition, reading fluency also depends on executive functions to coordinate various cognitive processes—such as the efficient and automatic activation of orthographic, phonological, and morphological knowledge.

These results align with the postulate of Berninger et al. (2001) that reading fluency draws on executive functions to manage multiple simultaneous demands. For example, working memory plausibly supports readers to retain information while relying on cognitive flexibility to shift across different components of the reading process, both of which are essential for successful reading outcomes. This finding has practical implications for practitioners as it suggests that strengths in EFs can compensate for weaknesses in reading fluency which indicates importance for attending to both domains in instruction. As expected, and in line with previous findings, this study confirms that reading fluency increases with age in typically developing children (Hurks et al., 2010; Kavé, 2006; Kavé et al., 2008; Sauzéon et al., 2004). However, what can be inferred from this finding is that age does not appear to be the main determinant of successful reading fluency in 8- and 10-year-olds, as the mediation analyses show that if executive functions are weak, age alone will not suffice to ensure satisfactory reading fluency regardless of children's age. Similar findings were reported by Nguyen et al. (2020) in a study examining 9-15-year old children who found that EFs played a potentially interactive-compensatory role in reading fluency, allowing readers to identify miscues and allow them to self correct them. The authors suggest that poorer EFs are associated with production of more miscues, having better EF is related to a higher probability of self-correcting such reading errors.

The results of this study also show that EF's are distinct components as the correlation between each core component is low to moderate. This is in line with the general consensus on the view that in infancy and early childhood years, EFs are an undifferentiated factor, which later breaks down into discretely related basic EF components ("unity but diversity" model by (Friedman and Miyake, 2017). Empirical studies have also confirmed this view by showing that the three core EFs are highly correlated in preschoolers, (e.g., Marzocchi & Mingozzi, 2022; Wiebe et al., 2008). Our finding on the distinct role of each EFs is in line with the study of Duan et al. (2010) examining EFs in children 10–11 years and confirming the hypothesis on the process of increasing functional specialization of neural systems, initially undifferentiated (Karmiloff-Smith, 1994). Thus based on this finding of the present study it can be inferred that the shared elements of EFs are less present in school-aged children as compared to younger children, and that each of the core EFs must be measured with isolated measures in this population. The present finding highlights the unique developmental trajectories of specific EF components during early to middle childhood. In contrast to the view of unity of EF subcomponents (Hughes et al., 2010; Shing et al., 2010; Tsujimoto et al., 2007; Wiebe et al., 2008; 2011), these findings support the differentiation of EFs into distinct components. Thus, our results contribute to the research on EFs by suggesting distinct developmental trajectories for these components in early childhood rather than viewing EFs as a unified construct.

One finding of the current study is that age, directly and also indirectly through EFs, significantly predicted reading fluency in a language with highly transparent orthography, that of the Albanian language. This is surprising knowing that in a language which has a regular grapheme-phoneme mapping children are expected to develop fluent reading by age 6–7, and by ages 8–10 fluency would be fully and sufficiently developed (Florit & Cain, 2011). This finding contradicts findings from other transparent orthographic languages such as Finnish, where the direct effect of reading fluency on reading comprehension wanes after the early school years, suggesting early development of reading fluency (Torppa et al., 2016). However, it somehow replicates the findings on the slow development of reading fluency in the Dominican language, which has a transparent orthography. In this study it was found that fourth graders had not yet reached reading automaticity, as evidenced by their poor performance in Word Recognition (around 40 words per minute). Therefore, it appears that Albanian, similar to Dominican children, are taking longer to master reading fluency than children from other transparent orthographic languages. Overall, these findings suggest that while the cognitive pattern of reading development across orthographies could be similar, there could be other socio-economic factors and instructional factors that may affect the process. This is also supported by findings of this study of the significant moderation role played by children's family Social-economic status (SES) and Mother's education level.

One possible interpretation of these findings is that a threshold of reading fluency is necessary before EFs can be harnessed to produce strategic reading. EFs may be important to the other higher order processes that can fully come online only when readers are sufficiently fluent in turning print into speech. Automaticity theory not only indicates that dysfluent readers must actively switch their attention between word recognition and comprehension but also suggests that this process may be ultimately overwhelming and unsuccessful for many readers, given constraints on their working memory and other EFs. Our study extends prior findings by explicitly modeling the indirect contributions of EFs to reading fluency via age. By establishing statistically significant and small to moderate indirect contributions, we highlight EF's as key skills for the age-reading fluency relation.

Practical Implications

Overall, the present findings are entirely consistent with the view that executive functions are important domains that aid reading fluency in children. This view represents a potentially valuable starting point for identifying children who may struggle with reading—and for identifying possible ways of supporting children as they learn to read. Our moderation results are an evidence of the importance of external support, be it from educational systems via teachers and tutors, or via family routes such as parental support. Given that executive functions can be reliably assessed as early as age four, early evaluations may help identify children at risk for reading difficulties—allowing for timely, targeted support at the outset of reading instruction. An effective strategy is to have children practice reading aloud with opportunities for correction and guidance. Educators can support this by encouraging oral reading and providing targeted, specific feedback.

Regular progress monitoring further reinforces improvement in reading fluency. Repeated reading is another useful strategy that may prove to be better at aiding children's development of fluency (Kuhn, 2005). Padeliadu et al. (2021) found that implementation of a repeated reading fluency program was highly effective in children with reading difficulties speaking Greek, a highly transparent language. Thus, this strategy could also be applied with children struggling with reading fluency of other transparent orthography languages, such as Albanian. This is especially important in Kosovo context, considering continued unsatisfactory results obtained in the reading test of PISA. This is important as without developing reading fluency through practice, learners will continue to devote an excessive amount of attention to word recognition, leaving insufficient cognitive resources to focus on the meaning of the text (Stanovich, 1980).

Limitations of the Study

This study has some limitations to be addressed in future research. First, our focus on the population speaking a highly transparent language was designed to reflect the interaction of orthography with the EFs in predicting reading fluency skills. Future research should include samples of highly transparent, semi-transparent orthographies and opaque orthographies to compare data to better understand how children of the same age, examined by the same tasks vary in terms of their ability to read accurately and quickly. Second, because of practical constraints, we included single measures of updating, inhibition and cognitive flexibility, and a collective measure of all that of the TMT task. Future research should incorporate multiple measures for each component of executive functions (EFs) to enable the creation of latent variables specific to individual EF components. Additionally, it would be beneficial to examine other self-regulation constructs associated with EFs, such as organization and planning.

Conclusion

Examining executive functions offers a broader perspective on how children achieve reading success, why some may struggle, and how interventions can be most effectively designed to support them. The current work expands on EF research by highlighting their importance to reading fluency at both developmental points, that of 8 and 10 years of age. It further provides important insights on the development of reading fluency in a language with a highly transparent orthography. Overall the current findings suggest that interventions aiming to enhance reading skills should consider strategies to strengthen EFs, as age alone does not guarantee reading proficiency. Understanding the role of EFs for reading may be particularly important in populations with a high proportion at risk for reading difficulties, because it is for such students that one would seek to bolster achievement either directly (addressing reading) or indirectly (via EF) (Cirino et al., 2019).

Acknowledgments

The authors thank all the students who participated in the study.

Disclosure Statement

No potential competing interest was reported by the authors.

Research Ethics

This study was approved by both the University of Sheffield's Department of Psychology Ethics Committee and the Ministry of Education, Science and Technology of Kosovo.

Funding

This project was not funded by any agency or funding body.

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Data Availability Statement

The data are available from the authors upon request.

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Appendix A

Table A1. Serial mediation of the EF on the relationship between age and reading fluency.

Total effect (Age -> Reading Fluency)	Direct effect (Age -> Reading Fluency)	Relationship	Indirect effect	Confidence intervals Boot LLCI	Boot ULCI	*t*-statistic	Conclusion
.19 (.00)	.11 (.00)	(Age ->SA -> NBackTC -> TMT -> Reading Fluency	.07	.03	.12	3.13	Partial mediation

Table A2. Serial mediation of the NBackTC on the relationship between SA and TMT.

Total effect (SA -> TMT)	Direct effect (SA -> NBackTC -> TMT)	Relationship	Indirect effect	Confidence intervals Boot LLCI	Boot ULCI	*t*-statistic	Conclusion
−.26 (.59)	.10 (.83)	(SA ->NBackTC -> TMT	−.36	−.75	−.09	2.11	Full mediation, competitive

Table A3. Conditional effects of the focal predictor at values of the moderator(s).

SES	Effect	se	*t*	*P*	LLCI	ULCI
−6.5417	.3073	.0601	5.1103	.0000	.1886	.4260
−.5417	.2091	.0364	5.7412	.0000	.1372	.2811
5.4583	.1110	.0454	2.4425	.0156	.0213	.2007

Table A4. Conditional effects of the focal predictor at values of the moderator(s).

Mother Education	Effect	se	*t*	*p*	LLCI	ULCI
−1.0553	.2639	.0527	5.0078	.0000	.1598	.3679
.0000	.1869	.0353	5.2990	.0000	.1172	.2564
1.0553	.1099	.0485	2.2636	.0249	.0140	.2057

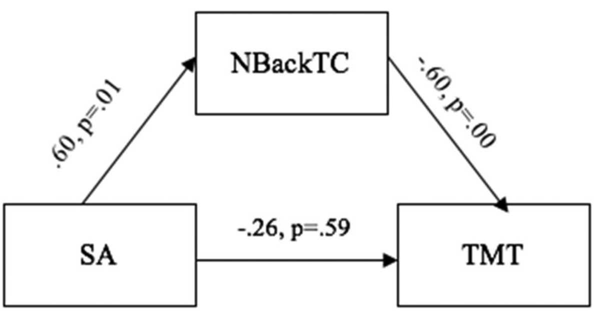

Figure A1. Serial model of the NbackTC mediation on the relationship between SA and TMT.

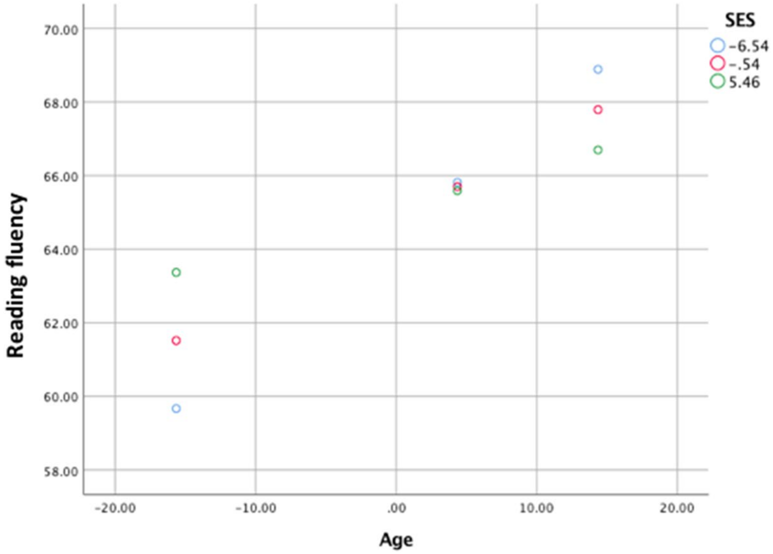

Figure A2. Age and socio-economic (SES) variables with mean centered values.

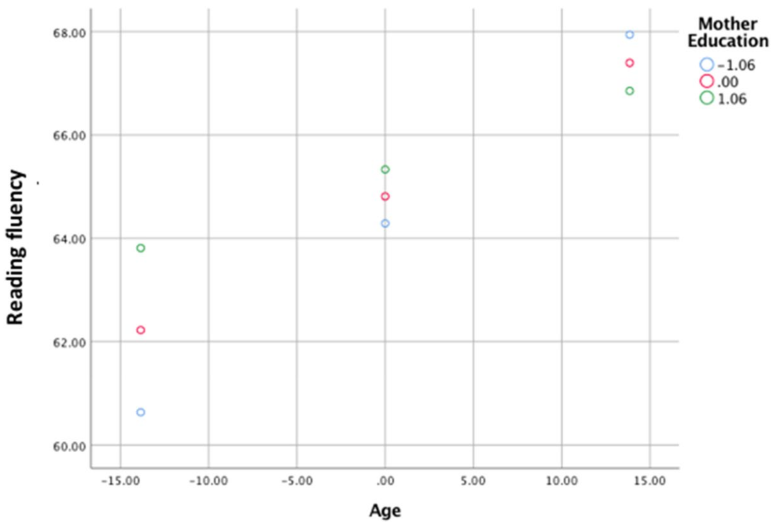

Figure A3. Age and Mother's education variables with mean centered values.