Objective Measures of Executive Functions as Predictors of Academic Achievement in Early Adolescence

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This study examined predictive relations of executive functions (EFs) with academic achievement in adolescents over a one-year period. One hundred and thirty-seven adolescents (53.3% girls, mean age 12.4 years) participated at T1, and 135 (51.8% girls) at T2. The Stroop Colour-Word, Backward Digit Span, and Trail Making Test were used to assess inhibition, working memory, and cognitive flexibility. Teachers provided data on the students' academic achievement. Results showed that a higher working memory span and a lower ratio score on Trail Making Test significantly predicted overall academic achievement and mathematics grades. In addition, a higher working memory span was associated with better grades in Slovenian language at T1, while cognitive flexibility predicted the respective grades at T2. However, no significant relationship was found between Stroop interference and academic achievement. The findings are discussed in the context of previous studies, and recommendations are made for improving EFs in the school context.

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Objektivne mere izvršilnih funkcij kot napovedniki učne uspešnosti v zgodnjem mladostništvu

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Ključne besede:
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delovni spomin

V raziskavi smo preučili napovedne zveze izvršilnih funkcij (IF) z učno uspešnostjo mladostnikov v obdobju enega leta. Ob začetku raziskave (Č1) je sodelovalo 137 mladostnikov (53,3 % deklet, povprečna starost 12,4 leta), eno leto kasneje (Č2) pa 135 mladostnikov (51,8 % deklet). Za oceno inhibicije, delovnega spomina in spoznavne prožnosti smo uporabili Stroopov barvno-besedni test, nalogo neposrednega pomnjenja števil nazaj in test sledenja. Podatke o učni uspešnosti mladostnikov so podali razredniki/razredničarke. Rezultati so pokazali, da obseg delovnega spomina in nižji razmernostni dosežek pri testu sledenja napovedujeta splošno učno uspešnost in ocene iz matematike. Večji obseg delovnega spomina se je povezoval z višjimi ocenami pri slovenščini (Č1), spoznavna prožnost pa je prav tako napovedovala višje ocene pri slovenščini v Č2. Med Stroopovo interferenco in učno uspešnostjo nismo prepoznali značilnih napovednih zvez. Ugotovitve smo interpretirali v kontekstu predhodnih študij in podali priporočila za spodbujanje IF v šolskem kontekstu.

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1 Introduction

Studies of executive functions in the fields of developmental psychology, neuroscience, and education have grown over the recent years. This increased attention stems from findings that emphasize the crucial role of these cognitive processes in various domains of a child's life, including cognitive and social development, development of independence, and academic achievement (Diamond, 2012). Defined as higher-order cognitive abilities, executive functions enable individuals independent and goal-directed behaviour (Blakemore et al., 2010; Lezak, 2004). They encompass a range of abilities, from adaptive thinking, updating and mentally manipulating information, inhibiting irrelevant stimuli, self-regulation, and the ability to plan and adjust behaviour in response to different contexts (Best & Miller, 2010). The development of executive functions, affected by the prefrontal cortex, undergoes rapid progression from early childhood until emerging adulthood (Goldstein et al., 2014; McCloskey et al., 2009).

The contemporary theoretical framework (e.g. Diamond, 2006; Miyake et al., 2000) proposes executive functions as a hierarchical construct and emphasizes three core components: inhibition, working memory, and cognitive flexibility. The interplay between these components facilitates progress in skills, such as planning, problem-solving, and adaptability in dynamic situations (Diamond, 2006). Given their importance, it is not surprising that these cognitive processes are instrumental in educational environments, where students are expected to sustain attention and manage different cognitive and behavioural challenges (Blair & Razza, 2007).

1.1 Inhibition

Inhibition, or inhibitory control, is the ability to regulate attention, thinking, behaviour, and emotion by consciously selecting desired stimuli and suppressing distractions. Central to inhibitory control is self-control, essential for resisting temptations, avoiding impulsive actions, and maintaining task consistency despite distractions (Diamond, 2013). Inhibition skills develop rapidly in childhood and further advance during early adolescence due to changes in the prefrontal cortex and axonal myelination (Anderson et al., 2001). These skills are vital for development of other EFs, such as working memory and cognitive flexibility. Laboratory tasks, including paradigms such as the Stroop task, the Go/No-Go task, the Flanker task, and the Anti-saccade task (for a review, see Diamond, 2013), are mainly used to assess inhibitory control (Fosco et al., 2019).

1.2 Working memory

Working memory is a temporary storage system for perceived and processed information and facilitates content retention (Koritnik et al., 2014). It differs from short-term memory in that it stores perceived information and retrieves previously stored information from long-term memory. In addition, working memory allows for the manipulation of stored information under the supervision of the dorsolateral area in the frontal cortex (Gathercole et al., 2004). The working memory system underpins various cognitive functions such as language comprehension, calculation, task reorganization, information updating and decision-making (Diamond, 2013). Development of working memory starts in infancy, with marked improvements after age seven. By this age, children's working memory in terms of organization and strategy resembles that of adults, although their method of storing information continues to evolve (Gómez et al., 2018). Standard assessments to measure working memory include the backward digit span and N-back task, which demand high selective and sustained attention (for a review, see Diamond, 2013).

1.3 Cognitive flexibility

Cognitive flexibility involves considering several concepts simultaneously and switching between them. It allows one to adapt problem-solving approaches and adjust to new requirements or rules (Best & Miller, 2010). This ability relies on inhibition skills and working memory and supports thinking across boundaries and finding multiple solutions to problems. Cognitive flexibility undergoes rapid development in early childhood, primarily due to the exceptional adaptability and malleability of the cerebral cortex (Diamond, 2012). Switching between tasks is typically mastered by children around age 11, but cognitive flexibility continues to develop during adolescence and adulthood (Buttelmann & Karbach, 2017; Huizinga & van der Molen, 2007). Task-switching and set-shifting tasks, such as the Wisconsin Card Sorting Task or Trail Making Test, are commonly used to assess cognitive flexibility (for a review see Diamond, 2013).

1.4 Executive functions and academic achievement

Recent research shows that goal setting, planning, and organization skills are critical to school success (Huizinga et al., 2018). Numerous studies (e.g. Best et al., 2009; Miller & Hinshaw, 2010) highlight the profound effects of executive functions on academic success in typical and atypical children and adolescents. Researchers (e.g. Blair & Razza, 2007; Miller & Hinshaw, 2010) have found a relationship between measures of executive functions (namely inhibition, working memory, and cognitive flexibility) and early childhood achievement in mathematics and reading. Specifically, inhibition and working memory associate with achievement in these subjects in early childhood and first grade, whereas executive attentional control is more related to mathematical achievement in middle childhood (Duncan et al., 2007).

Similar results were found in late childhood and early adolescence studies. For example, van der Sluis et al. (2007) reported a positive relation between performance in updating, reading, arithmetic, and non-verbal reasoning in students aged nine to twelve. Task-switching ability was associated with improved non-verbal reasoning and reading. St. Clair-Thompson and Gathercole (2006) found that executive updating correlated with adolescents' verbal and visuospatial working memory tasks. In addition, working memory was closely related to English and mathematics grades, while inhibition was associated with grades in English, mathematics, and science. Ahmed et al. (2019) also underscored the predictability of working memory and emphasized its importance for academic achievement from early childhood to adolescence.

1.5 Objectives

Much of the research has focused on executive function and academic achievement in childhood, but scarce studies focus on adolescents (e.g. St Clair-Thompson & Gathercole, 2006). The relationship between the various components of executive functions and academic achievement in this age period calls for further exploration to offer findings that are crucial for educators and policymakers. In addition, the variety of objective measures used to assess specific components of executive functions in adolescents makes it challenging to directly compare results across different national and cultural contexts (Nyongesa et al., 2019; Poon, 2018). Based on the three predominant objective measures—namely, the Stroop Colour and

Word Test (SCWT) for inhibition, the Digit Span Backwards Task for working memory, and the Trail Making Test for cognitive flexibility (see Nyongesa et al., 2019 for details)—our study aimed to investigate the predictive relations of executive functions with adolescents' overall academic achievement and their school grades in specific subjects, i.e. in Slovenian language, mathematics, and foreign language. Moreover, we investigated these relations in both the current academic year and one year later.

2 Method

2.1 Participants

In the study, we assessed adolescents at two measurement occasions. At the time of the first measurement (T1), 137 students participated (M_{age} = 12.4 years, *SD* = 9 months); 73 were girls (53.3%) and 64 were boys (46.7%). At T1, these participants were in the 6th (38%), 7th (35.7%), or 8th (26.2%) grade of a nine-year elementary school in Slovenia, which enrols students aged 6 to 15 years. Regarding writing tasks, 91.2% were right-handed, 6.6% were left-handed, and one participant was ambidextrous. Only adolescents without special needs were included in the study to avoid bias in test results. One year later (T2), 135 students (51.8% girls) of the initial sample were re-assessed; two students had transferred to another school. Classroom teachers provided data on academic achievement for all participating students.

2.2 Measures

Objective assessment of executive functions was conducted using the PEBL computer program (The Psychology Experiment Building Language; PEBL; Mueller, 2013) - version 2.0 for MS Windows operating systems (http://pebl.sourceforge.net/).

The Stroop Colour-Word Task (SCWT; Stroop, 1935, as cited in MacLeod, 1991) is a well-established instrument to assess response inhibition, selective attention, and resistance to distracting stimuli in children and adolescents. Within the PEBL program it operates via manual responses using keyboard keys. Words are displayed sequentially on the computer screen, requiring participants to respond immediately. The participant's task was to name the colour (red, blue, green, or yellow) of the word or symbol displayed, which could be congruent or incongruent with its meaning. There were three scenarios: neutral (control stimuli without a word, e.g. the symbol XXXX displayed in one of the four colours), congruent (the meaning matched the colour, e.g. the word green written in green colour), and incongruent (the colour differed from the meaning, e.g, the word green written in red colour). Each scenario included 48 trials. The variable of our interest was Stroop interference (i.e. Stroop effect), calculated as the discrepancy in average reaction time between incongruent and congruent trials. Lower interference values indicate higher levels of response inhibition (MacLeod, 1991).

The Backward Digit Span (BDS) is a widely used measure to assess working memory in individuals of various ages, including children, adolescents, and adults. It has been used in both clinical settings and research (Lezak et al., 2004; Poon, 2018). Participants in this computer-based task repeat a series of numbers in reverse order. For successful recall, individuals must suppress distractions, retain the number sequence in working memory, and input it backward (e.g. 3-7-6-9 becomes 9-6-7-3). Our participants began with a series of three numbers in a sequence. The number of displayed numbers increased when the participant successfully repeated at least one of two series of displayed numbers of equal length. The key variable of the task is the number of units correctly recalled in reverse order.

The Trail Making Test (TMT; Reitan, 1958; as cited in Arbuthnott & Frank, 2000) has two parts. Part A (TMT-A) measures psychomotor speed and visual attention. In its computer version, 25 circles are arranged on the screen, which participants connect sequentially using numbers (1-2-3-4). Part B (TMT-B) assesses executive function, specifically cognitive flexibility. The task is to alternately connect numbers (1 to 13) and letters (A to L) in the correct order (e.g. 1-A-2-B). Participants connect the circles in both parts by clicking on the subsequent number or letter with a computer mouse. The key variable of the task is the time it takes the participant to complete each subtest. A ratio score between Part B and Part A (TMT-B/TMT-A) has been shown the most appropriate measure of cognitive flexibility (Holfelder et al., 2020). A lower score indicates greater cognitive flexibility, whereas ratio scores of TMT-B/TMT-A > 3 indicate difficulties in cognitive switching (Arbuthnott & Frank, 2000).

Academic achievement. In the study, individual final grades in three main school subjects (i.e. Slovenian, mathematics, and a foreign language) were considered. In addition, overall academic achievement was calculated by averaging the adolescents' final grades in these subjects at the end of the current school year (T1) and one year later (T2). According to Slovenia's educational structure, student achievement is measured quantitatively from 1 (insufficient) to 5 (excellent). Data on the participants' academic achievement in this study were collected directly from their classroom teachers at T1 and T2.

2.3 Procedure

The Faculty of Arts Ethics Committee at the University of Ljubljana in Slovenia approved this study (approval no. 153-2019). Before the study, we linguistically adapted the PEBL program's measures. After obtaining informed parental consent and verbal consent from the adolescents, the assessment was conducted in a controlled environment, either in a classroom or the school counsellor's office. Each session lasted no more than 30 minutes. Prior to the assessment, the adolescents received clear verbal and on-screen instructions and completed trial runs. Classroom teachers provided the adolescents' final grades in Slovenian, mathematics, and foreign language at T1 and T2. The adolescents did not receive any financial or other compensation for their participation. On the contrary, classroom teachers received a certificate for their one-year participation. To ensure participant confidentiality, demographic data such as age, gender, school grades and assessments at T1 and T2 were stored using a unique research code system.

2.4 Statistical analyses

Data was analyzed using SPSS Statistics for Windows, Version 27.0. In the first step, we followed recommended methods for calculating Stroop interference and a TMT ratio score. Next, we performed descriptive statistics as well as Pearson correlations between variables, following Cohen's (1988) recommended thresholds of .10 (small), .30 (medium), and .50 (large). Series of multiple regression analyses using the Enter method included objective indicators of executive function as predictors and academic achievement (overall and subject-specific) at T1 and T2 as outcomes. Before regression analysis, data were tested for linearity, normal distribution, residuals' independence, homoscedasticity, non-multicollinearity, and absence of first-order autocorrelation (Field, 2013). The explanatory power of the model was categorized using Cohen's (1988) measures: small ($R^2 < 0.13$), medium ($R^2 = 0.13-0.25$), and large ($R^2 > 0.26$).

3 Results

Table 1: Descriptive statistics of executive function measures and academic achievement at T1 and T2

	N	*M*	*SD*	*Min*	*Max*	*Skewness*	*Kurtosis*
SCWT: INTF (incongruent−congruent)	134	119.23	87.69	–26.13	454.64	1.00	1.03
BDS: span score	137	4.76	1.23	2.00	8.00	0.04	–0.37
TMT ratio: TS-B/TS-A	137	1.68	0.57	0.66	4.07	1.52	3.23
Academic achievement – overall (T1)	137	3.90	0.88	1.67	5.00	–0.53	–0.68
Grade: Slovene	137	3.88	0.97	2.00	5.00	–0.44	–0.78
Grade: Mathematics	137	3.85	1.05	1.00	5.00	–0.42	–0.89
Grade: Foreign language	137	3.98	0.94	2.00	5.00	–0.54	–0.66
Academic achievement – overall (T2)	135	4.08	0.77	2.00	5.00	–0.58	–0.44
Grade: Slovene	135	4.09	0.90	2.00	5.00	–0.61	–0.59
Grade: Mathematics	135	4.00	1.00	2.00	5.00	–0.59	–0.81
Grade: Foreign language	135	4.16	0.85	2.00	5.00	–0.67	–0.41

Note. T1 = time 1. T2 = time 2 (one year later). SCWT = The Stroop Color-Word Task. INTF = interference (in milliseconds, two different conditions). BDS = The Backward Digit Span. TMT = The Trail Making Test (in seconds). TS-B/TS-A = ratio of time B to time A. Presented are final grades for each subject; overall academic achievement is the average of these grades.

Before analyses, the SCWT data were refined. We discarded response times below 200 ms and above 2000 ms, indicating anomalies (e.g. duplicate responses or external interference). We excluded data from three participants and retained accurate times within three standard deviations of each condition's average (Khng & Lee, 2014). Table 1 shows descriptive statistics for objective measures of executive function–

Stroop interference as an indicator of inhibition, working memory span, and ratio scores from the Trail-Making Test as an indicator of cognitive flexibility. The table also includes descriptive data on overall academic achievement and subject-specific grades at T1 and T2. There was a significant improvement in overall academic achievement from T1 to T2, $t\,(134) = -4.46$, $p < 0.001$.

Table 2 shows the correlations between measures of executive functions and indicators of academic achievement. All the statistically significant associations were modest in terms of effect size. Working memory span score correlated positively with overall achievement at T1 and T2 and with grades in Slovenian and mathematics but not in foreign language. A higher TMT ratio score, reflecting difficulties in cognitive flexibility, significantly correlated with lower grades, especially in mathematics. Stroop interference did not show any significant correlations with academic achievement.

Table 2: Correlation coefficients between executive function measures and indicators of academic performance at T1 and T2

	SCWT: INTF (incongruent−congruent)	BDS: span score	TMT ratio: TS-B/TS-A
Academic achievement – overall (T1)	–0.11	0.22*	–0.21*
Grade: Slovene	–0.09	0.22**	–0.12
Grade: Mathematics	–0.11	0.20*	–0.27**
Grade: Foreign language	–0.10	0.15	–0.15
Academic achievement – overall (T2)	–0.13	0.20*	–0.23**
Grade: Slovene	–0.07	0.15	–0.21*
Grade: Mathematics	–0.16	0.21*	–0.21*
Grade: Foreign language	–0.09	0.13	–0.16

Note. N = 132–134. T1 = time 1. T2 = time 2 (one year later). SCWT = The Stroop Color-Word Task. INTF = interference (in milliseconds, two different conditions). BDS = The Backward Digit Span. TMT = The Trail Making Test (in seconds). TS-B/TS-A = ratio of time B to time A. Pearson correlation coefficient, $^{*}p < 0.05$; $^{**}p < 0.01$.

Table 3 presents the summary of the regression analyses highlighting the role of executive functions in overall academic achievement. The independent predictors included in regression models are based on significant correlations (displayed in Table 2). Working memory, represented by the Backward Digit Span, consistently and positively predicts academic achievement at both T1 and T2. Conversely, a higher TS-B/ TS-A ratio score, indicating difficulties with cognitive flexibility, significantly predicts lower academic achievement during the same period. According to the recommendation by Cohen (1988), the effect size within the two multiple regression models was small, explaining 8.4% and 8.8% of the variance in the students' overall achievement at T1 and T2, respectively.

Table 3: Results of a series of multiple regression analyses: objective executive functions as predictors of overall academic achievement at T1 and T2

Dependent variables	Independent variables	β [95% CI]	*p*	R^2
Academic achievement – overall (T1)	BDS: span score	0.21 [0.03, 0.26]	0.014	0.084
	TS-B/TS-A	–0.19 [–0.54, –0.04]	0.022	
Academic achievement – overall (T2)	BDS: span score	0.19 [0.01, 0.22]	0.026	0.088
	TS-B/TS-A	–0.22 [–0.51, –0.08]	0.009	

Note. BDS = The Backward Digit Span. TS-B/TS-A = ratio of time B to time A (TMT). CI = confidence intervals [lower, upper].

As shown in Table 4, comparable outcomes were found when predicting subject-specific grades, particularly in mathematics. The regression models included independent predictors derived from significant correlations (displayed in Table 2). Both working memory and cognitive flexibility emerged as predictors of higher mathematical achievement among early adolescents. These two executive functions accounted for somewhat more mathematical achievement variability (10.6%) in the current year than in the following year (8.3%).

Table 4: Results of a series of multiple regression analyses: objective executive functions as predictors of mathematical achievement at T1 and T2

Dependent variables	Independent variables	β [95% CI]	*p*	R^2
Grade: Mathematics (T1)	BDS: span score	0.18 [0.02, 0.30]	0.026	0.106
	TS-B/TS-A	–0.26 [–0.77, –0.18]	0.002	
Grade: Mathematics (T2)	BDS: span score	0.20 [0.03, 0.30]	0.017	0.083
	TS-B/TS-A	–0.20 [–0.62, –0.05]	0.021	

Note. BDS = The Backward Digit Span. TS-B/TS-A = ratio of time B to time A (TMT). CI = confidence intervals [lower, upper].

Based on the results of separate simple regressions, we found that greater working memory span predicted higher final grades in Slovenian language at T1 (β = 0.22, 95% CI [0.05, 0.31], p = 0.009, R^2 = 0.050), but not at T2. However, a higher level of cognitive flexibility, as indicated by a lower ratio score on the Trail Making Test, predicted higher final grades in Slovenian language at T2 (β = –0.21, 95% CI [–0.60, –0.07], p = 0.013, R^2 = 0.046).

4 Discussion

Our study examined the predictive relations between objective measures of executive functions and academic performance in a sample of Slovenian adolescents. We used standard measures of the Stroop Color-Word Test, the Backward Digit Span, and the Trail Making Test to assess inhibition, working memory and cognitive flexibility, respectively. Classroom teachers reported on adolescents' academic performance using final grades in three subjects: Slovenian, mathematics, and a foreign language.

Consistent with our expectations, higher scores in the Backward Digit Span task (indicating greater working memory capacity) were significantly associated with academic achievement at both T1 and T2. Conversely, a higher ratio score on the Trail Making Test (indicating difficulties with cognitive flexibility) was associated with poorer academic achievement. Adolescents with greater working memory capacity and cognitive flexibility are better equipped to process and retain information, to adapt to changing tasks, and to integrate various concepts or ideas. These abilities are evident in enhanced proficiency in executing academic tasks and faster acquisition of new knowledge. Although we obtained small effects on achievement indicators, our findings concur with the previously documented association between working memory capacity and academic achievement in children and adolescents (Ahmed et al., 2019; Blair & Razza, 2007). Specifically, from ages six to twelve, working memory was suggested to be a salient predictor (e.g. Cortés Pascual et al., 2019), even surpassing intelligence in predicting academic success (Alloway, 2009).

The objective measures of executive function under study differentially relate to specific school subjects. In our sample, working memory and cognitive flexibility were likely to enhance mathematical achievement. For achievement in Slovenian language, the results were less consistent. Specifically, greater working memory span predicted higher grades at T1, whereas a lower ratio score on the Trail Making Test was associated with better grades at T2. We conclude that advanced working memory and cognitive flexibility enable students to process information more efficiently, to adjust mathematical strategies to different types of problems, to analyze and interpret texts more in-depth, and to write complex essays. These cognitive skills are, in turn, reflected in their overall academic performance. Previous research has also highlighted the role of working memory in mathematical achievement and of cognitive flexibility in children and adolescents' reading comprehension (e.g. van der Sluis et al., 2007; Yeniad et al., 2013).

In contrast, our results indicated that none of the objective measures of inhibition, working memory, or cognitive flexibility predicted final grades in a foreign language at either T1 or T2. These findings were unexpected, as various aspects of executive functions play integral roles in language skills, encompassing both production and comprehension. Specifically, previous research suggests that shifting might relate to the ability to monitor conversations; working memory could be involved in updating and monitoring information for sentence production and comprehension, as well as organizing episodic content; and inhibitory control might be vital for suppressing semantic competitors during word production or comprehension (Miyake et al., 2000; Mozeiko et al., 2011). While evidence underscores the influence of executive functions, notably working memory and cognitive flexibility, on academic achievement, their significance in foreign language grades might be marginal. This could be partly due to the Slovenian cultural context, where adolescents infrequently use foreign languages (e.g. English, or German), often constraining their use to specific school settings or informal peer-to-peer slang. A detailed assessment of linguistic aspects, including syntax, semantics, and pragmatics, would offer deeper insights into the relationship between executive functions and foreign language achievement (Shokrkon & Nicoladis, 2022).

The analysis of the relationship between Stroop interference and adolescents' academic outcomes revealed negative associations. Adolescents with longer reaction times, indicating increased interference, tended to achieve lower grades in Slovenian language, mathematics, foreign language, and overall. However, these associations were not statistically significant, which contradicts previous research highlighting the importance of self-control in academic achievements (Ahmad & Sultana, 2021; Duckworth et al., 2019). The divergence may be attributed to differences in calculating Stroop interference (for a review, see Scarpina & Tagini, 2017), limitations of this measure in assessing inhibition comprehensively, and potential challenges in capturing individual differences in cognitive abilities among early adolescents.

Our results highlight the importance of enhancing adolescents' executive skills to achieve better academic outcomes. Crucial interventions include working memory training (e.g. tasks that incrementally improve performance; Zelazo et al., 2016) and learning strategies for sorting and retention (e.g. mnemonics, acronyms, acrostics). Adolescents need to master task organization and prioritization, which can be accomplished with tools such as templates, mental models, or graphic organizers. Teachers can use problem-solving techniques to promote cognitive flexibility and incorporate diverse teaching methods (e.g. collaborative learning and peer discussions) to foster critical thinking (Meltzer, 2014).

Our research also emphasizes the need to explore cognitive predictors of academic achievement further. Consideration of final grades in different subjects would be beneficial, as each subject differs in content, teaching methods, and the required cognitive skills. We assume that increased cognitive flexibility facilitates successful understanding and application of complex concepts, particularly in science subjects (e.g. physics) and geography. Concerns about the objectivity of executive function measures can be addressed using multiple tasks to assess specific aspects of executive function and predict different academic outcomes. Future research should focus on the effectiveness of executive function strategies and their direct impact on academic success.

5 Conclusions

Our study highlights the critical role of executive functions, especially working memory and cognitive flexibility, in explaining academic achievement among Slovenian adolescents. Working memory and cognitive flexibility were robust predictors of their overall academic achievement. These executive skills enable students to process information efficiently, switch seamlessly between tasks, and assimilate different academic concepts, particularly in mathematics and Slovenian language. Results on foreign language performance were less conclusive, reflecting perhaps the complex nature of language learning in a specific cultural context and the need for a more accurate assessment of specific aspects of the language. The study also challenges previous assumptions about the Stroop interference measure and its relationship to academic achievement. Improving adolescents' executive skills, including their ability to adapt flexibly to different academic challenges, is critical for better academic outcomes. As we progress in understanding the cognitive predictors of academic achievement, it remains imperative to expand research on different school subjects and more sophisticated measures of executive functioning to optimize educational strategies for adolescents' academic success.

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