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Citation

Kovalčíková, I., Veerbeek, J., Vogelaar, B., Klimovic, M., & Gogová, E. (2024). Tracing progress in children's executive functioning and language abilities related to reading comprehension via ExeFun-READ intervention. *Education Sciences*, 14(3), 237.
doi:10.3390/educsci14030237

Version: Publisher's Version

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Downloaded from: <https://hdl.handle.net/1887/4176762>

Note: To cite this publication please use the final published version (if applicable).

Article

Tracing Progress in Children's Executive Functioning and Language Abilities Related to Reading Comprehension via ExeFun-READ Intervention

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Abstract: One important internal factor influencing reading comprehension is a child's executive functioning. The primary objective of this paper is to evaluate the effectiveness of a cognitive stimulation program, ExeFun-READ (a program focusing on executive functioning stimulation via the L1 (Slovak language) curriculum with a specific focus on enhancing reading comprehension). The program is explicitly based on the assumed bi-directional relationship between executive functioning and language abilities related to reading comprehension. The program is domain-specific; the curriculum of L1 (Slovak) is a curricular area in which cognitive mediation occurs. The study will investigate whether the domain-specific ExeFun-READ intervention had a positive effect on children's executive functioning and language subcomponents of reading comprehension. Keeping in mind ecological validity, ExeFun-READ was designed primarily for educational purposes, specifically professional tutoring for low-performing students. The intervention consists of 30 units; each unit lasts for 45–60 min. A stimulation unit approximates a teaching unit rather than a clinical experimental intervention. In total, 151 low-performing students attending grade four from seven elementary schools took part in the project. The study employs a pre-test–training–post-test design with three conditions: experimental, active control, and passive control. In the current study, the intervention led to improved language abilities related to reading comprehension. Significant improvements were found in vocabulary (semantic knowledge), completion of sentences (syntactic knowledge), and classification of terms (verbal fluency and inferencing) in the group of children that received the ExeFun-READ intervention. In terms of executive functioning, the improvement only extended to switching fluency.

Keywords: reading comprehension; language ability; L1; executive functioning; Exefun-READ intervention



Citation: Kovalčíková, I.; Veerbeek, J.; Vogelaar, B.; Klimovič, M.; Gogová, E. Tracing Progress in Children's Executive Functioning and Language Abilities Related to Reading Comprehension via ExeFun-READ Intervention. *Educ. Sci.* **2024**, *14*, 237. <https://doi.org/10.3390/educsci14030237>

Academic Editors: Dongbo Zhang and Lawrence Jun Zhang

Received: 16 September 2023

Revised: 14 February 2024

Accepted: 21 February 2024

Published: 25 February 2024



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1. Introduction

The fact that the ability to learn is dependent upon the ability to process information from a text [1,2] emphasizes the importance of research on text comprehension. In the theory of text comprehension, various models of comprehension have been created so far (see, for example, Alvermann et al. (2013) [3] and Zápotočná, (2012) [4]). The first, frequently analyzed in the literature, is the Simple View of Reading (SVR) [5] model of understanding the read text. This model defines two basic components of reading comprehension. The first is decoding, which includes perceptual and phonological processes; the second component is the understanding of text, with which the child has gained experience even before

mastering elementary reading. The two basic components of the model (decoding and understanding) are further divided by the following subcomponents according to Oakhill et al. (2015) [6]. Decoding is represented by knowledge of phoneme–grapheme correspondence, decoding accuracy, and decoding automaticity. Comprehension occurs through activating lexical meanings, understanding sentences, making inferences, monitoring comprehension, and understanding text structure. In the SVR model, the decoding and comprehension components are in a multiplicative relationship. However, some authors argue that the multiplicative relationship is not absolute, but depends on several factors [1]. One factor is the age of children. When children start learning to read, decoding burdens their cognitive capacity at the expense of the comprehension processes [7]. A meta-analysis showed that there is a strong correlation between word recognition and reading comprehension in eight- to ten-year-old children [8]. In meta-analytic procedures, decoding skills were found to account for 55% of the variance in children’s reading comprehension scores [9]. This correlation weakens as the children get older. In another interactional model of comprehension components, Tennent (2015) divides comprehension components into three areas, emphasizing their mutual interaction: (1) constructing lexical and syntactic meanings; (2) general and domain-specific knowledge of the recipient; (3) cognitive and metacognitive processes, which include memory, making inferences, and monitoring understanding [7].

Research in cognitive psychology [10] and cognitive linguistics [11] created significant impulses for the investigation of text comprehension at the beginning of the millennium. Currently, more attention is being paid to the interdisciplinary linking of text comprehension and a student’s cognitive capacity [2]. One important internal factor influencing reading comprehension concerns the child’s executive functioning [12]. Executive functioning as a construct comes from the field of neuropsychology and is a product of the observation of specific neurological disorders and their behavioral manifestations. The term “executive functioning” generally refers to the mechanism by which performance is optimized in situations requiring the operation of a number of cognitive processes [13]. Executive functions are often defined as a set of interrelated functions that enable purposeful, goal-directed behavior [14], and are seen as crucial for successful academic achievement [15]. There are multiple models that attempt to describe the form and conceptual framework of executive functioning. The models differ in which of the executive functions are seen as most fundamental and structurally important: inhibition, or self-regulation [16] of the attention control system [17], working memory [18], planning [19], or the construct of cognitive flexibility [20]. It has also been confirmed in research that executive functioning is a group of interconnected but at the same time significantly autonomous processes developing from around the age of nine [21]. Shallice (in Walsch, 1978) briefly summarized three types of situations that require the involvement of executive functions, namely: (1) new or unknown circumstances for which routine behavioral or cognitive patterns do not yet exist, (2) if the task is too complex, (3) when the task requires the integration of several sources of information [22]. The scholastic process of intentional learning, which includes reading comprehension, fulfills all these conditions. If the child’s level of executive functioning is low, then in the case of any of these three situations, the child’s cognitive functioning is likely to become disorganized, undirected, and thus naturally ineffective [23].

With regard to reading comprehension, it was found that both lower- and higher-order executive functions have an impact on different reading comprehension processes. Specifically, working memory, a lower-order executive function, was found to influence comprehension and integrating knowledge [24]. Cognitive flexibility, another lower-order function, was found to play a role for students with reading difficulties [25,26]. In addition, higher-order functions, such as attentional control [26] and planning, are crucial for decoding and reading comprehension and influence how readers plan, direct, select, and organize the available cognitive structures and processes necessary for comprehension [27]. Moreover, metacognition and self-regulation are important in monitoring and controlling comprehension [28]. For example, executive functions play a central role in integrating

visual and linguistic information, as well as in automatic recall of linguistic skills during reading [29].

However, it was suggested that the relationship between executive function and reading comprehension may be bi-directional [30], with gains in academic functioning predicting gains in executive functioning and vice versa [31]. Several studies have indicated that interventions aimed at strengthening children's executive functioning not only result in better executive functioning, but also transfer to their reading comprehension skills [32,33]. Similarly, another study proved that the reading comprehension program for fourth- and fifth-graders focusing specifically on metacognitive self-regulation could foster text comprehension [34].

2. The Current Study

In light of the aforementioned findings, training executive functioning within the curricular domain of L1 (Slovak) in primary education could lead to improvements in (1) language abilities related to reading comprehension and (2) executive functioning. The current study will employ a pre-test–training–post-test design with an experimental condition, an active control, and a passive control condition. As such, it will be investigated whether the domain-specific ExeFun-READ intervention had a positive effect on children's executive functioning and language abilities related to reading comprehension. In accordance with that objective, the first research question considered the effect of the ExeFun-READ program on children's executive functioning. It was hypothesized that children who received the ExeFun-READ intervention would show more improvement in their executive functions, specifically inhibitory behavior, cognitive flexibility/switching, processing speed, self-regulation, and attentional control, than the children in the active and passive control conditions [35–38].

The second research question investigated the effect of the ExeFun-READ program on children's language skills, considered a subcomponent of reading comprehension. In line with previous studies [34,39,40], it was expected that the children who received the ExeFun-READ program would show more improvement in language abilities related to reading comprehension (semantic knowledge, syntactic knowledge, verbal fluency/inferencing, verbal analogies) than those in the two control conditions.

The third research question examined the effect of the ExeFun-READ program on the relationship between children's executive functioning, language abilities related to reading comprehension, and school performance (specifically Slovak language). Considering that the ExeFun-READ program was assumed to improve children's executive functions and reading abilities [35–38], it was expected that the relationship between executive functioning and reading abilities on the one hand, and scholastic performance in L1 on the other, would become weaker for children who received the ExeFun-READ program, but not for those in the two control conditions.

The target group of the study were nine- to eleven-year-old low-performing pupils. This is the age at which children in Slovakia complete their primary education (fourth grade) and progress to the lower secondary stage. An unsatisfactory level of learning outcomes for Slovak fourth-graders is indicated in the results of the Progress in International Reading Literacy Study (PIRLS) [41].

2.1. Materials and Methods

2.1.1. Participants

Seven mainstream elementary schools were involved in the project. The school participation in the project was preceded by meetings with school principals and teachers. The schools were selected on the basis of pragmatic criteria; there was a history of cooperation between the research team and school management in previous educational events and research projects. A cross-section of schools was involved. Schools from larger towns, smaller towns and rural areas were integrated into the project.

Three hundred and seventy-four (374) low-performing pupils, attending Grade 4 took part in the pre-tests. A low-performing pupil is understood, in the context of this paper, as a pupil who does not achieve optimal academic performance. According to The Instructional Guidelines no. 22/2011 for the assessment of primary school pupils (Ministry of Education, Science, Research and Sport of Slovak Republic, 2011), a pupil's performance in each school subject (in the Slovak Republic) is classified on the following 5-point grading scale: 1—excellent, 2—commendable, 3—good, 4—sufficient, and 5—insufficient. A low-performing pupil is defined in this chapter as a pupil who attains grades 3—(good), 4—(sufficient), or 5—(insufficient) in the school performance summative assessment at the end of academic year in Slovak Language (mother tongue) and Mathematics. For the purposes of identifying low-performing students, the following 3-step-procedure was applied in the research design. Step 1: Based on the end-of-year certificate (marks of pupils in individual subjects at the end of the school year), pupils who achieved average to below-average performance in the two main subjects of the primary education curriculum (Slovak language and Mathematics) were identified. The pupils who did not speak Slovak as a first language and/or had any behavioral, emotional, or learning difficulties were excluded from the study. Step 2: the identified pupils were subjected to pre-measuring of their level of executive functioning, language skills, and reading. Step 3: Out of the total number of 374, 151 pupils were selected and involved in the intervention study. The selection criteria were equal scores in (1) pre-test measures in executive functioning and (2) measures in reading. To measure the level of executive functioning, the D-KEFS battery was used [42]. The Reading Test, another tool for the equalization of the research sample [43], provided information on reading speed, error rate, number and quality of errors, and level of comprehension of the read text. Based on the results of pre-measures of executive functioning and reading skills, by mixture of equalization and random selection, 151 children were divided into trios. In the trios were pupils with equal scores in executive functioning as well as equal scores in reading quality. Following pre-test data, children with equal scores were randomly allocated to one of the three condition groups—experimental group (group 1), active control group (group 2), and passive control group (group 3). As a result of equalization and random selection, in each group there were pupils with approximately the same level of measured indicators. For research purposes, data obtained from Slovak children in the age range of 9 to 11 years were used. The average age of participants was $M = 10.82$ years ($SD = 0.651$). There were several reasons for choosing this age category. Based on the knowledge of developmental neuropsychology, this age is the ontogenetic stage when the frontal lobes of a child's brain begin to mature enough to be able to provide relatively effective mediation in the area of executive functioning (especially in the domain of cognition) [20]. Ten school psychologists, members of the research team, administered executive functioning tests. The reading test as well as the language abilities tests were administered by research team members with expertise in L1 didactics. All instruments were administered in a clinical setting in the school that the pupil attended. Informed parental consent was obtained for all subjects involved in the study. Anonymity of the participants was ensured by registration through the subject coding system. Only members of the research team had access to the data. No external data collection and evaluation agencies were contracted. The division of participants can be found in Table 1.

Table 1. Number of participants by group and sex.

Condition	Boy	Girl	Total
Experimental	25	25	50
(active) control 1	29	22	51
(passive) control 2	24	26	50
Total	78	73	151

2.1.2. Design and Procedure

The study utilized a pre-test–intervention–post-test experimental design with three conditions: an experimental group (Group 1), active control group (Group 2), and passive control group (Group 3). There was a 3.5-month interval between the pre-test and post-test.

Group 1 was administered the original domain-specific intervention program ExeFun-READ (30 units; each unit 45–60 min). Trained university students studying for a master's degree in teacher training acted as administrators. The intervention was implemented in paired stimulation—that is, one administrator worked for 30 h with one pair of pupils. Twenty-five (25) pairs of pupils and 25 administrators were involved in the intervention. In total, 750 intervention hours (25 pairs $\times$ 30 h) were implemented within the experimental group. The interventions were implemented in the school environment during extracurricular time in the afternoon.

In Group 2, the teachers employed at the participating school worked with a regular L1 (Slovak language) textbook, giving 30 extra lessons of stimulation in the language domain following the regular national curriculum. In other words, the Slovak language curriculum was delivered in 30 extra lessons, without any specific regard to stimulation of executive functioning. In this group, the teacher worked with 7-member groups of pupils, in the school environment during extracurricular time in the afternoon.

Group 3 did not perform any additional tasks.

2.1.3. Materials

Executive functioning (EF). To assess the children's level of EF, the Delis–Kaplan Executive Function System (D–KEFS) [42] test battery was used. The D–KEFS test battery was adapted for use with the Slovak population, and the psychometric characteristics were tested and described by Ferjenčík (2015) [44]. The internal consistency was below 0.70 in the individual indicators of all battery tests, which from a psychometric point of view tends to be considered as the lower limit of “good” reliability. (For the calculation, either the internal consistency estimation via Cronbach's alpha coefficient or Split-half S-Brown test reliability estimation was used [42,44]). The individual D–KEFS battery indicators showed moderately high correlations with the W-J battery indicators [44]. In this study, the following subtests from the D–KEFS battery were used: (1) D–KEFS trail-making test—a test of attention organization and flexibility in five test conditions, capable of abstracting interference factors of visual searching and motor speed; (2) D–KEFS verbal fluency, which measures cognitive flexibility and ability to fluently generate verbal responses to letter prompts and categories within 60 s; (3) D–KEFS design fluency test, a test of figural fluency and cognitive flexibility (in three control conditions) in the visual domain; (4) D–KEFS color-word interference test, a version of the Stroop test in four test conditions that measures the ability to inhibit “learned” behavioral responses. Each of the incorporated D–KEFS tests contained 4–5 subtests, i.e., a total of 18 subtests for measuring executive functioning were used. Each of the 18 subtests had defined primary and secondary performance indicators, e.g., raw score, scaled score, contrast score, and score for set-loss error. D–KEFS battery does not contain one composite score of executive functioning, nor the composite score of one measured executive function. Adhering to the D–KEFS administrator manual [42], various primary and secondary indicators of executive function performance were calculated.

Language abilities/subcomponents of comprehension. To assess this construct, the following instruments were used: 1. Cognitive Abilities Test (CogAT)—Verbal battery [45]. The reliability of the Cognitive Abilities Test Verbal battery was found to be good $\alpha = 0.85$ [46]. The following subtests of CogAT were used: (1) Vocabulary—this subtest reflects the range of vocabulary, especially passive vocabulary and flexibility of speech use; (2) Completion of sentences, which indicates speech-logical thinking and general knowledge, as to properly manage the task it is necessary to define and understand the meaning of the presented concepts; (3) Classification of terms, which evaluates the ability of abstraction, inferential thinking, conceptualization, as well as verbal fluency. It reflects the scope and accuracy of the logical arrangement of verbal knowledge; (4) Verbal analogies reflect the level

of understanding of the relationships between verbal concepts and categories, logical reasoning in a verbal context and combinational abilities [46]. Each of the 4 subtests contains 60 items; each subtest offers one composite score by adding up the performance in the individual items.

ExeFun-READ stimulation program in the linguistic domain. The ExeFun-READ program is domain-specific. Linguistic/language material and reading in L1 are curricular areas in which cognitive stimulation occurs. To monitor current knowledge in the subject area, the following intervention programs targeting reading comprehension were studied as well: Reciprocal Teaching [47], Modified Reciprocal Teaching [48], POSSE (Predict—Organize—Search—Summarize—Evaluate) [49], the PREP (The PASS Reading Enhancement Program) [50], and PHAST (Phonological and Strategy Training) [51]. These programs can be collectively called cognitive training of reading comprehension [41,52].

The basic criterion for the domain-specific design of ExeFun Read intervention units was the multi-level nature of text comprehension. The emphasis was placed on components that, according to Tennant [7], Oakhill and Cain (2008) [53], and Oakhill et al. (2015) [6], can have an impact on reading comprehension. Stimulus units in a hierarchical sequence reflect on (1) the construction of lexical and syntactic meanings; (2) general and domain-specific knowledge of the recipient; (3) cognitive and metacognitive processes, memory, making inferences, and monitoring comprehension. This was reflected in designing the program content, in the selection of language/linguistic stimulus material, in the construction of particular tasks, and in operationally defining the form of administration in the educational context.

Domain-specific focus. It was taken into account that reading comprehension is predicted by different underlying language skills and knowledge. Vocabulary knowledge is strongly correlated with reading comprehension [6,39,54–56]. Several studies have shown that vocabulary is a strong predictor of the development of reading comprehension in the early years of school [57,58]. As Oakhill and Cain (2012) stated, like vocabulary, grammatical skills that are assessed with measures of syntactic awareness predict reading comprehension [39]. Furthermore, in research by Ortiz et al. (2021), it was confirmed that the relationship between syntax and reading comprehension was moderated by oral vocabulary [59]. Similarly, Brimo et al. (2017) proved that students' syntactic knowledge directly accounted for significant variance in reading comprehension [60]. In order to stimulate these specific component skills of reading comprehension, the domain-specific content was divided into modules. It contained 4 different, consecutive modules symbolically named as Word, Sentence, Paragraph, and Text, reflecting the multilevel structure of the text as well as the subskills influencing reading comprehension. Each module consisted of a set of graded tasks. The criteria for the grading and hierarchical organization of the tasks were based on cognitive analysis of the task. The level of the task's cognitive difficulty was indicated following two criteria—working memory load and level of abstraction. The modules were further divided into sections. Respecting the interaction model of text comprehension components, the structure of the program was designed as follows in Table 2.

Domain-general focus. While designing the program, it was taken into account that apart from vocabulary, grammatical, and syntactic knowledge, a number of higher-order discourse skills are likely to contribute to the development of reading comprehension. These skills include inference, understanding the text structure, and metacognitive skills manifested in comprehension monitoring [1]. The program has been structured in such a way to enable the administrator, during an individual interaction with a pupil, to both work with linguistic materials related to the school curriculum and, simultaneously, mediate executive, cognitive, and metacognitive processes in order to improve comprehension monitoring. For example, in the intervention, while the pupil gathered information, the administrator–pupil interaction was focused on the aim of stimulating the student's attention control, precise focus, and visual perception of task stimulus materials as cards with words, sentences, pictures, parts of the texts, etc. The administrators typically asked questions such as: *What do you see in front of you? What do we call these items, these things?*

What is this task about? What do you think you have to do? How are you going to do this task? While solving tasks during the intervention, while working with the text, metacognitive self-regulation was targeted at cognitive planning, strategic thinking, inhibitory control, and questions such as the following were asked: Planning: *What do you need to do to solve the problem? What approach should you use? What is the strategy? What is your plan? How do you start? How can you remember this text?* Inhibitory control: *What do you have to avoid doing? What mistakes do you have to avoid? What do you have to pay attention to in order to solve the task correctly?*

Table 2. Structure of the ExeFun-READ program.

Module/ Linguistic Material	Unit	Part Language Skills/Cognitive Focus	Recommended Number of Lessons
Word	1	Vocabulary/grammatical knowledge Juggle with a word: Word and morphemes comparison, categorization, grouping, word-formation motivation	3–4
Word	2	Vocabulary knowledge Juggle with a word: Cross-classification (similarities and differences), concepts teaching	2
Word/Sentence	3	Vocabulary/Syntactic knowledge How to better remember words and sentences: Attention control and memory	3–4
Sentence	4	Syntactic knowledge Juggle with a sentence: Deductive-hypothetical thinking, inferential thinking	5–6
Sentence	5	Syntactic knowledge Juggle with a sentence: Paraphrasing	2–3
Sentence	6	Syntactic knowledge/inferencing Juggle with a sentence: Co-referential relations between sentences	2–3
Paragraph	7	Understanding the text structure/ Juggle with a paragraph: Text analysis and comprehension	3–4
Text	8	Comprehension monitoring Juggle with a text: Self-regulation and pre-reading metacognitive strategies	3–4
Text	9	Comprehension monitoring Juggle with a text: Text decoding and comprehension, reading metacognitive strategies	6–7

The intervention was carried out 2–3 times a week. This frequency reflected the capacities of the school, pupils, and administrators. The intervention was implemented beyond the time scope of compulsory teaching. However, in the case of applying the program, the frequency of the intervention can be modified. Systematicity, regularity, and minimization of time gaps between units should be considered. ExeFun-READ represents material enabling professional tutoring of the pupil throughout the school year. The pilot intervention consisted of 30 units lasting 45–60 min in a pair stimulation. The full version of the program in the form of methodological material for teachers is described elsewhere [61].

Members of the research team performed regular supervision of the administration process at schools. Observation of the intervention was the basis of supervision. Three main aspects were considered: (1) the administrator’s activities with the pupil—the process of stimulation, (2) the stimulation material, and (3) the pupil’s response to it. Field supervision enabled the immediate formulation of conclusions and recommendations for the further course of intervention, as well as modifications of stimulation units. The results of the supervision were analyzed at subsequent administrator training sessions.

2.2. Results

2.2.1. Preliminary Analyses

Initial analyses were used to determine any a priori differences between groups. First, a Multivariate ANOVA (MANOVA) was used to determine whether the groups differed in terms of executive functions on the pre-test, with TMT motor speed time, letter fluency, category fluency, switching fluency, design fluency, and Stroop interference as the dependent variables, and condition (experimental, control 1, control 2) as a between-subjects factor. The results showed no significant multivariate effect for condition ($F(12, 280) = 1.23$, $p = 0.262$, $\eta_p^2 = 0.05$), indicating the groups did not significantly differ in scores for executive functioning. Next, to test for potential differences in language abilities related to reading comprehension on the pre-test, a second Multivariate ANOVA was conducted. Again, condition (experimental, control 1, control 2) was included as a between-subjects factor. Dependent variables in this analysis were vocabulary, completion of sentences, classification of terms, and verbal analogies. Multivariate analyses showed a significant effect for condition ($F(8, 288) = 5.97$, $p < 0.001$, $\eta_p^2 = 0.14$). Univariate tests showed significant effects on vocabulary ($F(2, 147) = 16.33$, $p < 0.001$, $\eta_p^2 = 0.18$), completion of sentences ($F(2, 147) = 18.47$, $p < 0.001$, $\eta_p^2 = 0.20$), classification of terms ($F(2, 147) = 8.57$, $p < 0.001$, $\eta_p^2 = 0.10$), and verbal analogies ($F(2, 147) = 6.51$, $p = 0.002$, $\eta_p^2 = 0.08$). Post hoc Bonferroni analyses showed significant differences for all measures between the experimental condition and the control 1 group (vocabulary $p < 0.001$, completion of sentences $p < 0.001$, classification of terms $p = 0.002$, and verbal analogies $p = 0.028$), and between the experimental condition and the control 2 group (vocabulary $p < 0.001$, completion of sentences $p < 0.001$, classification of terms $p < 0.001$, and verbal analogies $p = 0.002$). On all measures, the experimental group scored lower than the two control conditions (see also Table 3 pre-test scores). The control 1 and control 2 groups did not differ significantly (vocabulary $p = 1.000$, completion of sentences $p = 0.439$, classification of terms $p = 1.000$, and verbal analogies $p = 1.000$).

Table 3. Basic statistics for scores on all executive function and language abilities measures pre- and post-test.

		Pre-Test			Post-Test		
		Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Executive functions							
TMT motor speed time	<i>M (SD)</i>	61.18 (34.76)	53.78 (25.67)	52.85 (26.66)	45.53 (19.96)	44.92 (26.42)	38.40 (16.97)
Letter Fluency	<i>M (SD)</i>	13.88 (5.23)	15.02 (5.84)	14.40 (6.54)	17.61 (6.07)	17.38 (6.16)	17.79 (6.85)
Category fluency	<i>M (SD)</i>	24.20 (4.62)	24.54 (4.67)	23.17 (5.11)	28.37 (5.25)	26.98 (5.94)	26.13 (6.27)
Switching fluency	<i>M (SD)</i>	5.73 (2.83)	6.56 (2.61)	6.77 (2.99)	7.78 (2.60)	6.62 (3.06)	6.81 (2.66)
Design Fluency	<i>M (SD)</i>	7.45 (2.79)	7.06 (2.80)	7.72 (2.25)	8.35 (2.28)	9.04 (3.17)	10.15 (3.05)
Stroop interference	<i>M (SD)</i>	91.47 (22.00)	88.00 (19.04)	90.34 (17.20)	74.20 (17.04)	75.62 (19.37)	73.45 (17.04)
Reading abilities							
Vocabulary	<i>M (SD)</i>	14.29 (4.74)	18.28 (3.88)	18.93 (3.90)	18.29 (3.36)	18.42 (4.95)	18.62 (5.03)
Completion of sentences	<i>M (SD)</i>	14.59 (5.73)	18.36 (3.82)	19.76 (3.30)	18.55 (3.44)	19.54 (4.17)	20.67 (3.20)
Classification of terms	<i>M (SD)</i>	15.73 (3.97)	18.28 (3.60)	19.04 (3.10)	18.00 (3.71)	18.96 (4.29)	18.58 (3.47)
Verbal analogies	<i>M (SD)</i>	10.37 (4.08)	12.54 (4.00)	13.64 (4.66)	12.67 (4.06)	14.94 (4.62)	15.36 (5.03)

2.2.2. Effects of Training on Executive Function

The first research question was focused on the effects of the ExeFun-READ intervention on children's executive functioning, expecting more progress in executive functioning as a result of the intervention program compared to children in the control groups. The effects of the intervention on children's executive functioning were investigated through a repeated measures (RM) MANOVA. In this analysis, time (pre-test, post-test) was included

as a within-subjects factor, and condition (experimental, control 1, control 2) as a between-subjects factor. Dependent variables in this analysis were TMT motor speed time, letter fluency, category fluency, switching fluency, design fluency, and Stroop interference. The results are presented in Table 4. Basic statistics for the different variables are provided in Table 3. The multivariate Time effect was significant ($\lambda = 0.37$, $F(6,138) = 38.61$, $p < 0.001$, $\eta_p^2 = 0.63$), indicating that, in general, children showed progress on the measurements from pre-test to post-test (see Table 3 for basic statistics). Additionally, the effect of Time $\times$ Condition was significant ($\lambda = 0.85$, $F(12,276) = 1.91$, $p = 0.033$, $\eta_p^2 = 0.08$), indicating, in combination with examination of the mean scores (see Table 3), that children in the experimental group showed larger progress than children in the two control groups.

Table 4. Multivariate and univariate RM MANOVA outcomes for executive functioning.

	Wilk's λ	F	p	η_p^2
Multivariate effects				
Time	0.37	38.61	<0.001	0.63
Time $\times$ Condition	0.85	1.91	0.033	0.08
Univariate effects				
Time				
TMT motor speed time		38.00	<0.001	0.21
Letter fluency		54.60	<0.001	0.28
Category fluency		51.82	<0.001	0.27
Switching fluency		7.42	0.007	0.05
Design fluency		44.51	<0.001	0.24
Stroop interference		121.86	<0.001	0.46
Time $\times$ Condition				
TMT motor speed time		1.00	0.369	0.01
Letter fluency		0.95	0.390	0.01
Category fluency		1.35	0.263	0.02
Switching fluency		6.42	0.002	0.08
Design fluency		2.91	0.058	0.04
Stroop interference		1.27	0.285	0.02

Further inspection of the univariate effects revealed that the children showed progress from pre-test to post-test on all measures. However, a significant group difference was only found in switching fluency ($F(2,143) = 6.42$, $p = 0.002$, $\eta_p^2 = 0.08$). This is also reflected in the group means, as Group 1 ($\Delta M = 2.05$) showed larger progress over time when compared to Group 2 ($\Delta M = 0.06$) and Group 3 ($\Delta M = 0.04$). Partially in line with the hypotheses, children who received the ExeFun-READ intervention showed more progress in their switching fluency than children in the two control conditions. However, this effect was not seen on TMT motor speed time, letter fluency, category fluency, design fluency, and Stroop interference.

2.2.3. Effects of Training on Language Abilities Related to Reading Comprehension

The second research question was focused on the effects of the ExeFun-READ intervention on children's language subskills related to reading comprehension, expecting more progress in these language subskills as a result of the intervention program compared to children in the control groups. In order to investigate the effects of the intervention on language abilities related to reading comprehension, a second repeated measures (RM) MANOVA was conducted. In this analysis, time (pre-test, post-test) was included as a within-subjects factor, and condition (experimental, control 1, control 2) as a between-subjects factor. Dependent variables in this analysis were vocabulary, completion of sentences, classification of terms, and verbal analogies. The results are presented in Table 5. Basic statistics for the different variables are provided in Table 3. The multivariate Time effect was significant ($\lambda = 0.68$, $F(4,138) = 16.11$, $p < 0.001$, $\eta_p^2 = 0.32$), indicating that, in general, children showed progress on the measurements from pre-test to post-test. Additionally, the effect of

Time $\times$ Condition was significant ($\lambda = 0.81$, $F(8,276) = 3.94$, $p < 0.001$, $\eta_p^2 = 0.10$), indicating, upon examining the mean scores, that children in the experimental group showed greater progress than children in the two control groups.

Table 5. Multivariate and univariate RM MANOVA outcomes for language abilities.

	Wilk's λ	F	p	η_p^2
Multivariate effects				
Time	0.68	16.11	<0.001	0.32
Time $\times$ Condition	0.81	3.94	<0.001	0.10
Univariate effects				
Time				
Vocabulary		9.79	0.002	0.07
Completion of sentences		29.03	<0.001	0.17
Classification of terms		5.12	0.025	0.04
Verbal analogies		46.32	<0.001	0.25
Time $\times$ Condition				
Vocabulary		11.32	<0.001	0.14
Completion of sentences		6.82	0.001	0.09
Classification of terms		4.64	0.011	0.06
Verbal analogies		0.46	0.634	0.01

Further inspection of the univariate effects revealed that the children showed progress from pre-test to post-test on all measures. Additionally, a difference in progress over time between conditions was found for vocabulary ($F(2,141) = 11.32$, $p < 0.001$, $\eta_p^2 = 0.14$), completion of sentences ($F(2,141) = 6.82$, $p = 0.001$, $\eta_p^2 = 0.09$), and classification of terms ($F(2,141) = 4.64$, $p = 0.011$, $\eta_p^2 = 0.06$). The group means t again reflect these differences for vocabulary (Group 1 $\Delta M = 4.00$; Group 2 $\Delta M = 0.20$; Group 3 $\Delta M = -0.31$), completion of sentences (Group 1 $\Delta M = 3.96$; Group 2 $\Delta M = 1.18$; Group 3 $\Delta M = 0.91$), and classification of terms (Group 1 $\Delta M = 2.27$; Group 2 $\Delta M = 0.68$; Group 3 $\Delta M = -0.46$). Partly in line with the hypotheses, children who received the intervention showed significantly more progress from pre-test to post-test than children in the control conditions on most of the measures of language abilities involved in reading comprehension. For vocabulary, completion of sentences, and classification of terms, the experimental condition showed more progress than the two control conditions. However, this effect of intervention was not present for verbal analogies.

2.2.4. Effects of Training on Relationship with L1 School Results

The third research question examined the effect of the ExeFun-READ program on the relationship between children's executive functioning, language abilities related to reading comprehension, and school performance, expecting changes in relations from pre-test to post-test, as the training was expected to change the processes and skills involved in the different subskill before vs after the intervention. Correlations were used to test the relationship between children's executive functions and their Slovak language school results, and changes in this relationship as a result of training. Post-test measures for executive functions were split by condition, to test whether different patterns of relationships emerged as a result of training. The results are displayed in Table 6. On the pre-test, only TMT motor speed ($r(148) = -0.19$, $p = 0.022$), switching fluency ($r(148) = 0.28$, $p = 0.001$), and Stroop interference ($r(148) = -0.19$, $p = 0.021$) were significantly related to school results for reading. Post-test, significant correlations were only found for Group 2. Here, school results seemed to relate to TMT motor speed ($r(49) = -0.39$, $p = 0.004$), category fluency ($r(49) = 0.33$, $p = 0.017$), switching fluency ($r(49) = 0.35$, $p = 0.013$), and design fluency ($r(49) = 0.31$, $p = 0.027$).

Table 6. Correlations between pre-test and post-test measures and school results in L1.

	Pre-Test x School Result	Post-Test x School Result		
	Total	Group 1	Group 2	Group 3
Executive functions				
TMT motor speed time	−0.19 *	−0.20	−0.39 *	−0.02
Letter fluency	0.11	0.04	0.16	0.01
Category fluency	0.16	−0.07	0.33 *	0.22
Switching fluency	0.28 *	0.09	0.35 *	0.11
Design fluency	0.04	0.01	0.31 *	−0.03
Stroop interference	−0.19 *	−0.24	−0.17	−0.15
Reading abilities				
Vocabulary	0.43 *	0.35 *	0.33 *	0.35 *
Completion of sentences	0.54 *	0.33 *	0.37 *	0.50 *
Classification of terms	0.49 *	0.17	0.20	0.47 *
Verbal analogies	0.50 *	0.30 *	−0.28	0.39 *

* $p < 0.05$.

Additionally, correlations were used to test the relationship between children's language abilities related to reading comprehension and their Slovak language school results, and changes in this relationship as a result of training. Vocabulary, completion of sentences, classification of terms, and verbal analogies were used in the correlation analysis. Again, post-test measures were split by condition, to test whether different patterns of relationships emerged as a result of training. The results are displayed in Table 6. Pre-test, strong relationships were found between school results and vocabulary ($r(147) = 0.43$, $p < 0.001$), completion of sentences ($r(147) = 0.54$, $p < 0.001$), classification of terms ($r(147) = 0.49$, $p < 0.001$), and verbal analogies ($r(147) = 0.50$, $p < 0.001$). These relationships were also found in all three groups post-test for vocabulary and completion of sentences. However, the relationship between school results and classification of terms was only significant post-test for Group 3 ($r(43) = 0.47$, $p = 0.001$). Furthermore, the relationship between school results and verbal analogies was only significant post-test for Group 1 ($r(47) = 0.30$, $p = 0.036$) and Group 3 ($r(43) = 0.39$, $p = 0.009$).

3. Discussion

The aim of the experimental research presented in this paper was to investigate whether the domain-specific ExeFun-READ intervention had a positive effect on children's executive functioning and language subcomponents of reading comprehension. The research design reflected several studies which indicated that interventions aimed at strengthening children's executive functioning not only result in better executive functioning, but also transfer to their reading comprehension skills [32,33].

The dependent variables in the experimental study were (1) executive functioning processes (inhibitory behavior, cognitive flexibility/switching, processing speed, self-regulation, and attentional control), and (2) language skills, considered as subcomponents of reading comprehension (semantic knowledge, syntactic knowledge, verbal fluency/inferencing, verbal analogies). School performance was the controlled variable.

The ExeFun-READ intervention was a domain-specific program in the linguistic domain. Linguistic/language material L1 (Slovak) was the curricular area in which cognitive stimulation occurred. ExeFun-READ was designed primarily for educational purposes, specifically professional tutoring for low-performing students. Intervention consisted of 30 units; each unit lasted for 45–60 min. The stimulation unit approximates a teaching unit rather than a clinical experimental intervention. Each unit was processed in detail into methodical material. The units contained worksheets for students as well as detailed methodological instructions for the teacher on how to work with educational materials.

3.1. Executive Functioning

The results of the current study showed positive effects of the ExeFun-READ intervention on children's executive functioning. Closer inspection, however, demonstrated that significant group differences were found only in switching fluency. As expected, the experimental group showed larger progress over time, compared to the active control and passive control groups. During the intervention, two types of cognitive flexibility were stimulated [62]: (1) reactive flexibility, which represents the ability to adapt one's reaction to changing situational conditions and task demands; (2) spontaneous flexibility, which is related to the content diversity of ideas and is associated with the concept of creativity. The intervention employed tasks related to switching fluency, such as sorting, grouping and categorizing letters, words, and phrases, and switching between categories based on phonetic, morphological, and semantic characteristics of words. For example, the principles of cross-classification of words and concepts were intentionally used [63]. Deliberate alternation of criteria for different levels of classification, sorting of language material, and practicing these skills appear to have led to increased performance in switching fluency. However, no significant group differences in improvement were found on the other measures of executive functioning, despite the focus of the ExeFun-READ program on further developing executive functions using linguistic materials. This finding could perhaps be explained by the domain-specific focus of the intervention, which may have led to under-stimulation of the executive functions not related to switching fluency, or a lack of transfer from practicing executive functions applied to the specific reading tasks to other more general tasks. Another possible interpretation of progress in executive functioning in both control groups could be related to a testing effect; retesting could be strongly influenced by learning and transfer.

3.2. Language Abilities Related to Reading Comprehension

Regarding the effects of the ExeFun-READ intervention on children's reading abilities, specified as language abilities represented by the subcomponents of reading comprehension, significant improvements were found in semantic knowledge/vocabulary, syntactic knowledge/completion of sentences, and verbal fluency/classification of terms in the group of children that received the ExeFun-READ intervention compared to children in the active and passive control groups. The intervention appeared effective in improving children's abilities in these different domains. Children's vocabulary skills and syntactic knowledge may have improved due to the two aspects of the intervention: (1) The intervention's domain-specific focus: in order to stimulate these specific component skills of reading comprehension, the domain-specific content was divided into modules. It contained four different, consecutive modules symbolically named as Word, Sentence, Paragraph, and Text, reflecting the multilevel structure of the text as well as the subskills influencing reading comprehension. This coordinated tossing of literary items could contribute to significant improvement in the language subcomponents of reading. Focus (2) of the intervention required verbalization of the processes involved in solving tasks. In turn, this may have enhanced practicing their active and passive vocabulary to describe objects (e.g., pictures) and states (e.g., feelings associated with success while solving tasks), define strategies, and clarify and summarize the information they have read.

Additionally, improvements in syntactic knowledge will likely have resulted from the systematic focus on formulating coherent sentences within the intervention. In the intervention, sentences were viewed as the structural units of paragraphs and texts. In line with prior research on the effectiveness of metacognitive language stimulation programs [64,65], strategies for practicing analyzing texts, searching for keywords, and paraphrasing sentences and paragraphs of the educational text were included in the intervention, as they were expected to lead to improved reading comprehension, and may have been central to children's improvement in sentence completion. These results are in line with the research of Zhao and Guo (2021) [66], that showed the contribution of syntactic knowledge to reading comprehension.

The intervention also led to more improvement in classification of terms. Based on the principles described in the Concept Teaching Model [67], students were supported in making the transition from the concrete meaning of words to abstraction. The intervention included guided practice in categorizing word groups according to selected criteria of superordinate concepts and, vice versa, in concretization (e.g., when decoding the meanings of unknown words from the context).

However, no differences in improvement were found between the conditions on verbal analogies. This might in part be due to the nature of verbal analogies, which in addition to requiring language and reading abilities, are also dependent on inductive reasoning skills. Inductive reasoning or, more specifically, analogical reasoning, is a skill that is closely related to general cognitive abilities, and generally seen as a robust indication of general intelligence. It is closely related to more everyday skills such as problem-solving and transfer and requires abstraction of novel information that is relevant in a specific context and application of it in another [68,69]. The skills measured here may have been broader than just reading ability and may therefore have gone beyond the scope of the intervention.

The findings related to recorded progress in language subcomponents of reading comprehension; however, in the case of executive functioning, proven progress only in switching fluency in experimental conditions was not in line with Follmer's (2018) [30] study, which indicated there may be a bi-directional relationship between executive functioning and reading comprehension. An additional base for data interpretation can be found in the research results of Dolean, Lervag, Visu-Petra, and Melby-Lervag (2021) [70]. They found that executive functions did not have a significant direct effect on the development of reading comprehension in early readers beyond fluent decoding and oral language skills in languages with transparent orthography; only language skills could independently predict development of reading comprehension. According to the above-mentioned authors, these results also suggest that once children learn to decode well, their language skills (and not their executive functions) have a strong effect on the development of reading comprehension.

3.3. Relations with School Performance

In terms of relationships between school performance, executive functions, and language subcomponents of reading comprehension, some unexpected results were found. The intervention was based on research by Follmer (2018) [30], Fuhs et al. (2014) [31], Meixner, Warner, Lensing, Schiefele, and Elsner (2019) [71] and detailed a close relationship between executive functioning and academic functioning. This assumption was not reflected in the relationships between school results in L1 and executive functioning, as, except for the moderate relationship between switching fluency and reading, no or weak relationships were found between executive functions and summative school results in L1 (Slovak). This could either indicate that executive functions are not as closely related to performance in the language domain, reading comprehension included, as expected, or that the executive functioning measures utilized lacked sensitivity. However, taken together with the other results, this might also indicate the domain-specific nature of executive functions, as described above. Moreover, it was found that relationships between executive functions and school results were no longer found for post-test scores of both the experimental group and the passive control group and seemed to have strengthened for the active control group. A similar effect was seen in previous research with an experimental domain-specific intervention in mathematics [61], in which the active control group showed a similar pattern of relations with math subskills on the post-test as the general pattern portrayed on the pre-test, while both the experimental group and the passive control group showed far weaker relations. One of the possible interpretations of these nonlogical relations between the variables may be the reduced objectivity of the teacher's assessment of school performance. The school grade/mark as an indicator of school achievement should be replaced by more reliable methods of assessing school performance in further research.

3.4. Limitations

In addition to those mentioned above, some limitations were found in the current study. Implementation fidelity was not measured or monitored, which may have caused variability in implementations. The absence of the intervention items' reliability measures may appear to be a limitation. However, the research team's intention was not to prescribe and to validate a fully standardized unitary type of intervention. It turned out that this is not even possible in a real educational situation. On the contrary, the administrator was to understand the stimulating aspects of the program in the language domain on the one hand, and on the other hand to respond to the individualized needs as well responses of the pupil. A complete algorithmizing of intervention was not possible and not desired. In other words, the administrator was not led to reproduce mechanically the instructions designed by researchers in an identical format. The teacher was guided to be able to identify the proper level of difficulty for a specific item of the program, then, within the item, by scaffolding pull the students from the zone of current development to the zone of the proximal development. The intervention was implemented within the school environment. On the one hand, this speaks for strong ecological validity. However, this also led to limited time being devoted to implementation of the intervention, through constraints in the school time and the time teachers could devote to the intervention. As the intervention was implemented after classes, it may not always have been implemented in the ideal circumstances and students may not always have been in the position to give it sufficient priority.

A significant limitation of the research design is the absence of a direct measure of reading comprehension. Indirect indicators of progress in reading comprehension represented by language abilities—vocabulary/semantic knowledge, completion of sentence/syntactic awareness, verbal fluency/inferencing—were monitored. With regards to the measurement of executive functions, it is possible that D-KEFS, because of learning and transfer effects, could be unsuitable for experimental studies. It may be better suited for clinical assessment of executive performance. Additional measures of executive functioning could also be applied; apart from the D-KEFS battery, behavioral rating scales assessing manifestations of executive functioning in the school setting could be considered.

The program contains many concepts and variables. However, it is an intervention that is based on the needs of teachers' practice: it is implemented in educational practice, and the results of experimental verification should be directed to educational practice. They were not applied as in the case of a laboratory experiment, following the principles of intentional reduction in variables. The program should have been able to offer guidance on how to work with a low-performing student in a real school environment over a longer period of an entire school year and to know the basic principles and procedures for stimulating two essential factors of school performance: the quality of executive functioning and reading comprehension.

In conclusion, it could be stated that the primary intention of the research team was to create a tutoring program for low-performing pupils, in order to strengthen the processes of executive functioning and reading comprehension. The program was created so that it could be incorporated into the environment of a standard Slovak school. The current research found bidirectional relationships between reading ability and switching fluency, similar to those found in previous studies (Follmer, 2018; Meixner, Warner, Lensing, Schiefele, and Elsner, 2019; Fuhs et al., 2014) [30,31,71] but not in other executive functions. Further research should focus on the relationship between executive functioning and reading ability, and the practical value it offers for shaping reading interventions. In terms of effects on language abilities related to reading comprehension, the ExeFun-READ intervention showed promising results: improvements were found because of the intervention in relation language subcomponents manifested in reading comprehension. Although more research is necessary, implementation of this intervention may help improve children's reading abilities and consequently improve their educational opportunities.

Author Contributions: Conceptualization, I.K.; Methodology, I.K. and J.V.; Validation, M.K. and E.G.; Formal analysis, B.V.; Investigation, M.K. and E.G.; Resources, B.V.; Data curation, J.V. and B.V.; Writing—original draft, I.K.; Writing—review and editing, J.V.; Supervision, I.K.; Project administration, I.K. and M.K.; Funding acquisition, I.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by APVV (Slovak Research Agency of Ministry of Education, under the contract APVV-15-0273).

Institutional Review Board Statement: This research was designed with respect to The Code of Ethics of the American Educational Research Association, approved by the AERA Council in February 2011. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of the Faculty of Education of the University of Prešov under the number 2018/4 in February 2021.

Informed Consent Statement: Informed consent in the form of parental consent was obtained for all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to confidential information.

Conflicts of Interest: The authors declare no conflicts of interest.

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