



Research Article

Family Transmission of Executive Functions: Mix of Traditional and Citizen Science Research Approach

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ABSTRACT

The aim of this study was to examine the family transmission of executive functions deficits (working memory and inhibitory control) from parents to children, using a combination of traditional and citizen science research approaches. The final sample consisted of 110 families with two children (440 participants; 110 pairs of children, 110 fathers and 110 mothers). Children were preadolescent (6 to 10 years old; 24 pairs) or adolescent (11 to 15 years old; 86 pairs) siblings. The research results indicated that the inhibitory control of the mother is related to the inhibitory control of the younger child, and that the inhibitory control of the father is related to the inhibitory control of the older child in the family, regardless of developmental period. In the father-child relationship, it was revealed that there is a strong connection between parental and child working memory. On the other hand, there are significant interaction of mothers' working memory and age of children in the second-born child. Potential mechanisms of transmission were discussed, bearing in mind the specifics of mother's and father's involvement in raising children, as well as the potential direction of this research question towards the sphere of behavioral genetics and parenting styles.

Key words: citizen science, executive functions, family transmission, inhibition, working memory

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Executive Functions: Definition, Structure and Life-Span Perspective

Executive functions (EFs) represent a comprehensive concept that refers to the neurocognitive processes involved in the performance of conscious, purposeful and goal-directed behavior (Miyake et al., 2000). This domain of cognition has a self-regulatory and controlling role in the individual's behavior, and it enables focusing attention on specific tasks, successful problem solving and planning of future activities in everyday life. Contemporary research is consistent in conceptualizing EFs as a hierarchical construct, operationalized by a series of lower-order executive functions (Andreson 2008; Miyake et al., 2000), and the diversity of EFs was primarily confirmed in a large number of studies conducted on adult sample (for a review, see e.g., Borella et al., 2008; Jurado & Rosselli, 2007). Despite some inconsistencies (e.g., Roebbers et al., 2012), previous research most often confirms the multifactorial structure of EFs in children and adolescents (Huizinga et al., 2006; Van der Sluis et al., 2007). Certain inconsistencies in determining the number of factors arise from the use of different instruments for measuring EFs (e.g., Espy et al., 2004; Van der Sluis et al., 2007) and due to their development that does not end during the childhood and adolescence (Andreson, 2002; Huizinga et al., 2006).

Studies of children and adolescents, most often indicate their two-factor or three-factor structure (Lee et al., 2011; Van der Ven et al., 2012). In psychological research, the most common result is the separation of working memory and inhibitory control as the primary EFs during these developmental stages (Brocki & Bohlin, 2004; Lehto et al., 2003), and also across the adult life-span (Borella et al., 2008). Working memory, according to Barkley (Barkley, 1997), is a memory domain in charge of holding information while also allowing for its simultaneous manipulation. On the other hand, inhibitory control implies the ability to suppress, ignore, or eliminate distractors, as well as irrelevant content and automatic responses, in order to fully focus attention on the goal (Miyake et al., 2000). Both of these EF types significantly contribute to the general

cognitive functioning of both children and adults, but in slightly different manner.

Research shows that EFs, especially working memory and inhibition, are age-dependent, and that, starting from early childhood, they change during adolescence, adulthood and old age, through linear and/or quadratic development (Borrela et al., 2008; Ferguson et al., 2021; Leon-Carrion et al., 2004; McAuley & White, 2010). There still seems to be no consensus regarding whether EFs develop gradually (linearly) or abruptly (quadratically), depending on the age of the child, and comparing preadolescents with adolescents can potentially answer this question. The slight decline of working memory and inhibitory control begins during middle adulthood, and continues into an old age (Ferguson et al., 2021), as part of the natural aging process (Salthouse, 2010). Having in mind that the development of EFs does not end during the childhood and adolescence (e.g., Huizinga et al., 2006; Spencer et al., 2020), it seems crucial, but also challenging, to focus research on the discrepancy between children's EF' incompleting development and their parents' EF' slight drop in performance.

Family Transmission of Executive Functions: Parent-Child Dyads and Birth Order

Family transmission, broadly known as intergenerational transmission, refers to the process by which certain characteristics, behaviors, values, beliefs, and traits are passed down from one generation within a family to the next. It encompasses the transfer of various aspects of culture, socialization, and identity from parents or older family members to children or younger family members (Schönpflug, 2009). Family transmission can involve both genetic and environmental factors, and it plays a significant role in shaping individuals' development and identity (Deater-Deckard, 2014).

The results of contemporary research indicate that EFs are also subject to family transmission (e.g., Kim et al., 2021; Korucu et al., 2019; Tomlinson et al., 2022), and that this process is evident both at the youngest age (Cuevas et al., 2014; Kim et al., 2017), as well as in middle childhood and adolescence (Briant et al., 2017; Kim et al., 2021; Korucu et al., 2019). These results were documented

in research with neurocognitive tests (e.g., Cuevas et al., 2014; Jester et al., 2009; Kim et al., 2017; Kim et al., 2021), but also through questionnaire assessments (Korucu et al., 2019; Li et al., 2023). Briant et al. (2017) pointed to family transmission of working memory and inhibitory control from parents to adolescents, explaining this relationship through household chaos. Their results indicated that lower parent EFs predicted lower adolescent EFs, but only in the context of high-level chaos (Briant et al., 2017). The importance of the influence of microenvironmental factors was also suggested by other studies, which dealt with the role of parenting styles in childhood and adolescence (Bernier et al., 2012; Li et al., 2023), and some researchers have pointed out the importance of genetic factors (Tomlinson et al., 2022). On the other hand, some studies emphasize the effects of the macroenvironmental factors, such as immigration status, exposure to traumatic events, or significant risk and socioeconomic adversity (Chen et al., 2020; Kim et al., 2017). No matter the age group, nor the methods used to measure and operationalize EFs, all of the aforementioned research found that better/worse parental EFs is associated with improved/compromised child EFs, which is in line with transactional model of self-regulation development (Sameroff, 2010).

However, some research indicate that there may be a gender-based relationship between parental EFs, and children's EFs (e.g., Jester et al., 2009; Meuvissen & Carlson, 2015; Ribner et al., 2022). According to Jester et al. (2009), mothers contributed more variance to adolescents' EFs than fathers, although concrete measures of working memory and inhibitory control were not used in this study, rather EFs were viewed as one general measure. The same results are obtained on pre-school children (Li et al., 2023), but slightly different on toddlers (Ribner et al., 2022). These somewhat conflicting findings have demonstrated that the pathways of transmission from paternal or maternal EFs to a child's EFs may vary depending on the child's developmental stage, and recommended that additional attention should be dedicated to enhancing mothers' capacity for self-regulation. In contrary, Ribner et al. (2022) found an additive role of fathers' EFs, similar in magnitude to the role of mothers' EFs, but in toddler stage. It is also not unusual for studies to include only one parent, primarily the mother

(e.g., Distefano et al., 2018; Kim et al., 2021), or to include only one parent regardless of their gender (e.g., Briant et al., 2017; Chen et al., 2020). These studies also indicate the same process of family transmission of the EFs. Given that mothers have proven to be a more important factor in the family transmission of EFs, previous explanations have primarily focused on the fact that mothers are more involved in the care of the child, that they devote themselves more to children education and development compared to the father (Li et al., 2023), and that fathers more involve themselves in the entire process of caring for the child at the earliest age (Ribner et al., 2022).

A common finding in psychological research is that laterborn children perform less well on cognitive tests compared to first-born children and also have weaker life-work performances (e.g., Belmont & Marolla, 1973; Zajonc, 2001), although contemporary studies partially challenge these conclusions (e.g., Damian & Roberts, 2015; Damian & Spengler, 2020; Rohrer et al., 2015). Some, but not all, research results support the absence of differences in EFs between firstborn and laterborn siblings in preschool and elementary school age (Morgan et al., 2019; Park et al., 2018). On the other hand, there are results which indicate the existence of differences on EFs tests in favor of first-born child (Rochat et al., 2016; Mileva-Seitz et al., 2015), or that the number of children in the family (i.e. single child will have the most developed cognitive abilities because all the parents' attention is focused exclusively on them) is a much more important predictor of EFs than birth order (e.g., Rolan et al., 2018). Although we cannot strictly draw conclusions about how the connection of child and parent EFs are related to birth order, consulting a wider range of literature we can draw some assumptions. First-borns prioritize their families, accordingly identify more with their parents, and try to imitate them more than laterborn children (Pollet & Nettle, 2007; Rohde, 2003). Due to such a situation, it is expected that the identification of first-born children with their parents also takes place in the domain of EFs, and that the differences are maintained even in adult and old age (Holmgren et al., 2006). Laterborn children actually make up for the lack of skills with wider social support in order to attain/reach better adaptation (Salmon et al., 2016). In general, it seems that the similarity of first-born children's

traits, and thus probably EF, with parental traits, is affected by their greater orientation towards the family and achievement (family-achievement adjusted), unlike the latterborn children, who are more oriented towards the wider social environment (socially adjusted). However, these conclusions are drawn indirectly and require additional empirical verification.

Mixed Approach of Current Study

By reviewing the literature, it can be established that the body of research dealing with this topic is not extensive, and demands additional attention for at least three reasons: 1) the role of the father in the context of the family transmission of executive functions is mostly omitted in research; 2) there are different patterns of connection between parental EFs and child EFs depending on the child developmental stage; 3) unclear role of birth order in parent EFs and child EFs relations. Therefore, the aim of this study was to answer the question of the transmission of EFs from parents to children, depending on the developmental stage (child/adolescent), gender of parents (father/mother) and order of birth (first/second child). We assumed that mother's EFs will be more strongly related to children's EFs, with a certain amount of doubt when it comes to younger respondents where the father's active role was also expected, then that first-born children will have more pronounced EFs than second-born children, and that adolescent sample will have more pronounced EFs from children sample.

We tried to answer these questions by applying a specific approach to data collection that involves a traditional and a citizen science approach. The European Citizen Science Association's (2016) guiding principles for citizen science emphasize the importance of involving the general public in research projects that advance scientific understanding of significant phenomena. Like traditional research strategy, citizen science has flaws and biases that need to be managed (Kosmala et al., 2016). To the contrary, citizen science offers the chance for more public involvement and the democratization of science. Considering that the basis of our work is the potential improvement of children's upbringing and education, our strategy aimed to include citizen scientists-

volunteers, primarily people who are interested in social issues, as well as the parents. According to Haklay (2013) citizen science activities may vary, depending on motivation, from conceptualizing the research to simplified collecting the data. Considering that the author's project activities cover a wide range of psychological related variables, we expected that the topics we are already examining will be the primary focus of people who will apply to participate in the project in the role of scientist-volunteers. Upbringing is a life domain for which the public has already shown some kind of interest in some countries (e.g., Dolgaya, 2016; Yuldashev, 2022). Therefore, we expected that the data collected through the traditional method would be supplemented by the data collected through the citizen science approach.

Method

Sample

During two iterations of sample recruitment, a total of 153 families with two children applied for the research. After reviewing the consent of the participants and after treatment of missing data, the final sample consisted of 110 families (440 participants) from Serbia. We include families that had two children with an age difference of no more than 4 years, in order to keep the time interval between the children births at least partially under control, given that the conditions in which children grow up can differ and shape children's characteristics. Taking into account applied statistical analyses, the required effect size was set to $\eta^2 = 0.15$, with a statistical power of 0.95, and it was calculated that a sample size of 107 families may be appropriate for this research (Faul et al., 2009). The sample of children and their family members (6-10 years) consisted of 24 pairs ($\Sigma 48$) of siblings and their parents (24 mothers and 24 fathers). Mean age for older child was 9.78 years ($SD = 1.25$), and for younger was 8.33 years ($SD = 1.39$). Mean age for mothers was 32.5 years, and for fathers was 35 years. The sample of adolescents and their family members (11-15 years) consisted of 86 pairs ($\Sigma 172$) of siblings and their parents (86 mothers and 86 fathers). Mean age for older child was 13.03 years ($SD = 1.43$), and for younger was 10.84 years ($SD = 1.87$). Mean age for mothers was 35 years, and for fathers

was 40.5 years. A significant difference in the representation of the two age groups (children vs. adolescents) was detected, $\chi^2(1) = 28.51, p < .01$. In total sample, there were 24.1% male-male sibling diads, 23.3% female-female sibling diads ($\Sigma 47.4\%$ same sex dyads), and 52.6% female-male sibling diads.

Instruments

In this research, three parallel age-related forms of inventories were used to assess EF depending on the development stage of the participants:

Childhood Executive Functioning Inventory (CHEXI)

CHEXI (Thorell & Nyberg, 2008) is intended to measure problems in executive functioning in children of early elementary school age (6-10 years old) through assessment by parents. Answers are given on a five-point Likert scale (from 1 - *definitely not true* to 5 - *definitely true*), allowing parents to assess the extent to which the given statements are true for child. For the purposes of this research, both subscales were used: Inhibition (11 items, e.g., *Has a tendency to do things without first thinking about what could happen*, $\alpha = .68$) and Working Memory (13 items, e.g., *Has difficulty remembering lengthy instructions*; $\alpha = .72$) deficits. CHEXI has already been used in research in Serbian sample of children (Milovanović, 2021), where it showed satisfactory reliability. Answers to this questionnaire were provided by the parents of the child participants who were younger than 10 years.

Teenage Executive Functioning Inventory (TEXI)

TEXI (Thorell et al., 2020) uses a 5-point likert scale ranging from 1 ("*definitely not true*") to 5 ("*definitely true*") also in order to assess the Inhibition (11 items, e.g., *I am putting things off until the last minute*; $\alpha = .71$) and Working Memory (9 items, e.g., *Sometimes I am having difficulties remembering what I need to do in the middle of an activity*; $\alpha = .78$) deficits in teenagers (10-19 years), by self-report. TEXI is already successfully validated in Serbian sample of teenagers (Thorell et al., 2020).

Adult Executive Functioning Inventory (ADEXI)

The 14 items on the self-administered ADEXI scale (Holst & Thorell, 2018) also assess two EF domains. The Working Memory deficits measure consists of 9 items (e.g., *I have difficulty thinking ahead or learning from experience*; $\alpha = .79$), while the inhibition deficits measure consists of 5 items (e.g., *I have a tendency to do things without first thinking about what could happen*; $\alpha = .70$). ADEXI has already been used in Serbian sample of adults in previous research (Nikolašević et al., 2022), where it showed satisfactory reliability.

Data Collecting

Data collection was carried out in two ways. The traditional method was primarily used to collect primary data, during the project activities in which the authors of this paper were engaged (Smederevac et al., 2019). This involved examining the families that were in the database of registered respondents through an online platform, where family members filled in questionnaires, each for themselves, except for children under 10 years old, who were assessed by parent reports. Part of the sample was also collected by psychology students for which they received a certain number of points on Educational Psychology course. The second method of data collection involved a citizen science approach, which is now not uncommon approach on the Serbian research scene (e.g., Sadiković et al., 2020; Bila Dubaić et al., 2021). During 2021 and 2022, the authors organized webinars on psychological related topics that were considered to be of interest to citizens. A total of 26 citizens showed interest in this research topic and took active part in the project activities that entailed collecting data and dissemination of the results on social networks, promoting the research, motivating the families to complete the questionnaires, and, at the end, promoting the results through social networks. Final webinar was dedicated to topics that citizens-volunteers presented to a wider audience through online participation. During the entire process citizen scientists were mentored by and collaborated with the authors of this paper. The research was approved by the ethics committee of the author's institution (submission ID: 202010291658_SyRk). There is a list of the citizen scientists who contributed to

the study in the acknowledgement. Final data set and data instructions are deposited in the OSF (<https://osf.io/jgxz8/>). About 10% of the sample were collected through the citizen science approach.

Results

Descriptive Statistics

Descriptive parameters are shown in Table 1. It can be seen that the children have more pronounced EFs deficits than both parents, and that the mother has slightly higher scores on the ADEXI than the father. All variables are normally distributed, according to the Tabachnick and Fidell (2016) criteria: $-1.00 < Sk$ and $Ku < 1.00$. Considering the significantly different representation of children and adolescents in the sample, comparisons between family members were made using non-parametric statistical methods.

Table 1

Descriptive parameters of used measures

	Working Memory deficits				Inhibition deficits			
	M	SD	Sk	Ku	M	SD	Sk	Ku
First-born sibling	2.38	0.92	0.51	-0.43	2.86	0.82	0.29	-0.30
Second-born sibling	2.30	0.88	0.61	-0.22	2.87	0.79	0.17	0.17
Mother	2.12	0.80	0.75	0.49	2.52	0.83	0.83	-0.07
Father	2.03	0.80	0.81	0.35	2.48	0.91	0.91	-0.46

Differences between Groups of Participants and Pairwise Comparisons

According to the results of Friedman ANOVA test, due to the dependence of measures among family members (Tabachnick & Fidell, 2013), there is a statistically significant overall difference on the measure of Inhibition deficits between children and parents, $\chi^2 = 15.68$, $p < .01$. Pairwise comparisons

suggested that there is no difference between first-born and second-born children measures, $p = .95$, nor between mother and father measures, $p = .40$. In the sample of children it can be seen that differences between siblings on the Inhibition problems measure do not exist in both: children, $p = .50$, and adolescents, $p = .75$. However, there is significant differences between children and parents Inhibition deficit measures. First-born, $MR = 2.73$, $p < .01$, and second-born, $MR = 2.74$, $p < .01$, children have significantly higher Inhibition deficits in comparison to mothers' ($MR = 2.35$). The same case is evident in comparison of the first-born, $p < .01$, and second-born, $p < .01$, child with the fathers' measure of Inhibition deficits ($MR = 2.19$). There is also a statistically significant overall difference on the measure of Working Memory deficits between children and parents, $\chi^2 = 14.59$, $p < .01$. Pairwise comparisons suggested that there is no difference between children measures, $p = .42$, nor between mothers' and fathers' measures, $p = .11$. If the sample of children is viewed by age subgroups, it can be seen that differences between first- and second-born siblings on the Working Memory measure do not exist in both children, $p = .69$, and adolescents, $p = .39$. However, there are significant differences between children and parents working memory deficits measures. First-born, $MR = 2.72$, $p < .05$, and second-born, $MR = 2.69$, $p < .05$, children have significant higher deficits in Working Memory in comparison to mothers' ($MR = 2.45$). The same case is evident in comparison of the first-born, $p < .01$, and second-born, $p < .01$, children with the fathers' measure of Working Memory problems ($MR = 2.14$). A significant difference was also observed between children ($MR = 41.43$) and adolescents ($MR = 60.08$) on the working memory deficits measure (M-W U = 780.5, $p < .05$) in favor of adolescents, but that differences do not exist on inhibitory control deficits (M-W U = 945.0, $p = .28$).

Effects of Parental EF on Child EF

Due to positive and mild-to-strong intraclass correlation (Cohen, 1988) of EFs between children and parental measures (Table 2), we first tested the interaction effects of parental EFs on child EFs using MANOVA. We didn't get

interaction effect in the case of Inhibition deficits, $\lambda = .99$, $F = 0.32$, $p = .72$, $\eta^2 = .01$, nor in the case of Working memory deficits, $\lambda = .99$, $F = 0.41$, $p = .67$, $\eta^2 = .01$.

Table 2

Intraclass correlations between siblings and parents

	INH_s1	INH_s2	WM_s1	WM_s2	INH_m	INH_f	WM_m	WM_f
INH_s1	-	.43**	.78**	.43**	.32**	.37**	.22*	.45**
INH_s2	.02	-	.35**	.74**	.43**	.26*	.22*	.29**
WM_s1	.53**	-.06	-	.53**	.29**	.40**	.28**	.51**
WM_s2	-.12	.41*	.29	-	.49**	.34**	.35**	.45**
INH_m	.06	.26	.28	-.03	-	.53**	.61**	.54**
INH_f	.27	.26	-.13	-.18	-.01	-	.35**	.63**
WM_m	.41*	-.31	.36*	-.32	.21	.12	-	.54**
WM_f	.16	-.01	.24	-.03	-.15	.43*	.30	-

Notes. INH – inhibition deficits, WM – working memory deficits, s1/2 – first-born/second-born sibling, m – mother, f – father. Coefficients below diagonal refers to preadolescents, and above to adolescents. * $p < .05$. ** $p < .01$.

Due to that, we tested the effects of parental EFs on child EFs, with two sets of hierarchical regression analyses, with parental EFs as independent predictors. In the first step, age group of the child was included as a predictor variable, while we added EFs in the second step of the analysis. Criterion in both cases was one of the EF. The results in the context of Inhibition deficits are presented in Table 3.

Table 3

Hierarchical regression analysis: Inhibition deficits

	First-born sibling						Second-born sibling					
	Step 1			Step 2			Step 1			Step 2		
	β	t	p	β	t	p	β	t	p	β	t	p
Age group	.12	1.23	.22	.12	1.32	.19	.06	0.59	.56	.07	0.74	.46
M. Inhibition				.14	1.41	.16				.35	3.61	.00
F. Inhibition				.29	2.88	.01				.11	1.13	.26

Note. M – mother, F – father.

The results have shown that mothers' inhibition is significant predictor for the second-born child, while fathers' inhibition for the first-born. Age group (children – 1, adolescents – 2) did not play a significant role in determining the degree of inhibition in children and adolescents. By analyzing the interactions of children age group and father/mother inhibition in contribution of children inhibition, it was obtained that there is no significant interactive effect in the case of inhibition neither in the first-born (fathers' inhibition – $\beta = .01, t = .02, p = .99$; mothers' inhibition – $\beta = .18, t = .40, p = .69$) nor in the second-born (fathers' inhibition – $\beta = -.35, t = -.79, p = .43$; M. mothers' inhibition – $\beta = .33, t = .74, p = .46$) child. The obtained results indicate that greater problems in the father's inhibitory control contribute to the manifestation of the same problems in older sibling, while in the case of mothers, this happens when we talk about younger sibling. The results in the context of Working Memory deficits are presented in Table 4.

Table 4*Hierarchical regression analysis: Working Memory deficits*

	First-born sibling						Second-born sibling					
	Step 1			Step 2			Step 1			Step 2		
	β	t	p	β	t	p	β	t	p	β	t	p
Age group	.21	2.25	.03	.20	2.39	.02	.23	2.48	.02	.22	2.42	.02
M. WM				.10	0.98	.33				.08	.79	.43
F. WM				.40	4.10	.00				.31	3.05	.00

Note. M – mother, F – father; WM – Working Memory problems.

The results have shown that the measure of fathers' working memory problems is significant predictor for the both siblings, first-born and second-born, and that this counts more for adolescents than for children. The obtained results indicate that greater problems in the father's working memory contribute to the manifestation of the same problems in both children, and that it is more typical for the period of adolescence than for childhood. Mother's working memory deficits did not play a significant role in shaping children's working memory problems in any age groups. By analyzing the interactions of children age group and father/mother working memory in contribution of children working memory, it was obtained that there is no significant interactive effect in the case of working memory in the first-born (fathers' working memory – $\beta = 0.60$, $t = 1.45$, $p = .15$; M. Working memory – $\beta = -0.66$, $t = -1.46$, $p = .15$) child. However, there is a significant contribution of interaction in the second-born child in case of mothers ($\beta = 0.78$, $t = 2.11$, $p = .04$), but not in case of fathers ($\beta = 0.51$, $t = 1.19$, $p = .24$). By introducing the interaction, the unique contribution of the father's working memory drops significantly in case of second-born child ($\beta = -0.20$, $t = -0.48$, $p = .63$). In general, it seems that the mother's working memory is a significant factor of working memory in the adolescent second-born child.

Discussion

The purpose of this study was to provide a response to the question of whether executive functions (EFs) are transmitted from parents to children depending on the developmental stage, the gender of the parent, and the child's or adolescent's birth order using the mixed traditional-citizen science approach. We assumed that the mother's EF will be more strongly related to the children's EFs in comparison to father's EFs, that first-born children will have a more pronounced EF than second-born children, and that the adolescent sample will have a more pronounced EFs from the children sample. This study did partially confirm our assumptions, and provided new insight into the consideration of the relationship between parental and child EFs.

The findings of this study indicate that adolescents, compared to children, have more deficits in working memory, but not in inhibitory control. Suggested by some applied psychological research (e.g., Huizinga et al., 2006; Spencer, 2020), adolescents, who have a higher working memory capacity than children, use more sophisticated problem-solving techniques, filter out inappropriate stimuli beforehand, and quickly access the information they need from long-term memory. On the other hand, children, who have a lower working memory capacity, may use simpler task-solving techniques, do not filter out inappropriate responses beforehand, take longer to recall the information they need from long-term memory, and do not operate with more complex problem-solving techniques. Due to their increased use of additional, but redundant cognitive processes in daily life, adolescents with higher working memory capacities may be more susceptible to compromising the information processing, due to overloaded working memory. Children, with their lower working memory capacity, use mostly necessary and less demanding cognitive processes, and there are less chances of overloading the working memory with additional stimuli that could cause deficits in functioning. The absence of differences on inhibition deficits, as well as the existence of differences on working memory deficits that were obtained in this research, still leave the question of the development of executive functions (linear vs. quadratic) open for future researchers (Borrela et al., 2008; Leon-Carrion et al., 2004; McAuley &

White, 2010), who would conceptualize a longitudinal type design of this kind of research.

The absence of differences on EF deficit measures between first-born and second-born children can also be explained by the issue of (non)linear development of EF. Bearing in mind that the average age difference between siblings in our study was less than 2 years (1.82), this appears to be too small age difference in order to detect an increase or decrease in EFs, which is consistent with the results of some earlier studies (Morgan et al., 2019; Park et al., 2018). Other studies (Damian & Roberts, 2015; Damian & Spengler, 2020; Rohrer et al., 2015) suggest that minor birth order effects are obtained on cognitive, but primarily intelligence tests. Rohner et al. (2015) suggested that differences could be obtained in siblings with an age difference of less than five, but they add that those differences can be expected rather on some personality dimensions, due to potential competitiveness between siblings, than on cognitive measures. Additionally, differences have thus far been found more often on neuropsychological tests measuring EF than on self-reported or peer-rated measures.

Our assumptions about a stronger association of mothers' EFs with children's EFs were partially confirmed. We found that father's working memory deficits are associated with children's working memory deficits, especially in adolescence, regardless of birth order. However, after introducing the interaction with the age group of children into the model, the father's contribution is lost and only the mother's working memory effect prevails in the second-born sibling, and this case can be considered the most specific transmission. Mothers favor lastborn child over other children in the family, and they participate more in the educational process in children (Waizenhofer et al., 2004), which potentially contributes to the development of working memory through one of the mechanisms of transmission. However, for specific models of transmission it is necessary to conduct a longitudinal research, and to include some of the moderator or mediator variables that are not included in this research (e.g., parenting). On the other hand, mother's inhibition deficits were more strongly associated with younger sibling's inhibition deficits, and

father's with older sibling's inhibition deficits. At this point, it should be noted that a nuclear family twin design could probably provide a more complete answer for these results, given that it is evident that genes, shared and non-shared environment could shape children's EFs (Tomlinson et al., 2022). Some other studies outside the field of behavioral genetics offer other explanations. According to Gold et al. (2020) children may be more conscious of their fathers' participation in adolescence and middle childhood than in early childhood in the context of upbringing, and they may develop relationships based on common interests. The fact that effect sizes in this research were large suggests that adolescence may be a stage of life where the fathers' time investments may have a bigger impact in comparison to mothers' (Gold et al., 2020). These conclusions could be explained by assumption that in adolescence a greater closeness is formed between the interests of fathers and children through some home-based or outdoor activities which can accelerate the process of identification and working memory development (Gold et al., 2020). Adolescents, for instance, may have important life concerns in a way that appeals to fathers who are starting to sense their own developing role. This convergence of developmental requirements might provide a dynamic environment for the father, who is motivated to become more involved with the adolescent child because he is able to have a more companionable connection with, than is achievable with a children in the middle childhood (Bruce & Fox, 1999). According to Flouri and Buchanan (2003), and Su et al. (2017) fathers' involvement in childhood is linked to less internalizing and externalizing problems in adolescence, which, among other, could also includes deficits in working memory and its consequences. Therefore, another recommendation is to conduct longitudinal research, which would check the assumptions that joint father-child activities in adolescence can be carried out in earlier childhood, which could improve the EFs of children. When considering the results related to inhibition, the role of fathers is present only in older sibling, and role of mother in younger sibling, regardless of the age period. According to Hetherington & Stanley-Hagan (1999), fathers are more likely to be involved with older children than with younger ones in the family. Some studies indicate that fathers actually favor first-born child, and mother favor lastborn child over other

children in the family, and that they show greater (dys)functional participation in their upbringing (e.g., Salmon et al., 2016). Moreover, according to Deater-Deckard et al. (2010, 2012), parents with weak inhibitory abilities are more likely to lose their temper, and struggle to restrain their own impulsive thoughts and emotions, which maybe creates a harsh parenting and unstable environment for the development of child inhibition. Although there is a lack of empirical studies specifically exploring how parenting practices affect the transmission of EFs (Li et al., 2023), it seems that the development of a child's inhibitory control may be negatively impacted by these parents' propensity for negative or harsh parenting (e.g., Cuevas et al., 2014), which could arose as a consequence of weak inhibitory control. So, the parenting style should unquestionably be included as a significant factor in future studies, as well as some personal characteristics of children and parents such as intelligence or personality traits.

Limitations and Future Directions

Our study provides new and more precise insights into the specificity of familial transmission of EF in relation to developmental period, gender of parents and birth order through within-family design. Moreover, this is the first study in Serbia that mixes traditional and citizen science research approaches. Still, there are certain limitations of the study. First of all, number of children and adolescents was not even across two groups, and the gender of the children was not included in the analysis. Although some of the previous research indicates that there are no gender differences in the EF transmission patterns (e.g., Li et al., 2023), the absence of the child gender in this study is caused by the fact that several groups of siblings should be made: same-sex male, same-sex female, mixed-sex in which the brother is older than the sister, and mixed-sex in which the sister is older than the brother. We could not apply this approach due to a relatively small sample in general, and especially in combination with the developmental period (childhood vs adolescence). Therefore, future research should include a larger number of respondents, incorporation of complex analyses of nested data, so that these groups could

be formed and potential more specific forms of transmission of EF from parents to children could be seen.

Additionally, although citizen scientists showed interest in participating in the study, it seems that the percentage of citizen participants could be higher or at least the promotion of the results could be more visible to a wider audience, given that only about 10% of the respondents were gathered through the citizen science approach. When citizen scientists are actively involved in multiple levels of the research design, they therefore feel the research project is more their own and, relating more to the research project, and there is a greater motivation for participation. In future research, it would be highly valuable to include citizen scientists in the conceptualization of the research problem, setting of research questions, processing and analysis of research data, as Haklay (2013) suggested through the various stages of citizen participation. Nevertheless, this preliminary study indicates that the quality of data collected by citizen science methods does not lag behind the quality of data collected by the classical method, which speaks in favour of the fact that the citizen science approach is a valid and proven approach to the organization of scientific studies.

Finally, it seems that self-reported measures need to be supplemented with measures from neuropsychological tests, given that they do not suffer from social desirability problem. At the end, our results indicated that there are still at least three directions of development in this field: 1) direction towards behavioral genetics, i.e. twin and adoptive studies, and 2) inclusion of other variables in the process of family transmission of EF, such as family size, personality traits, parenting styles and intelligence, and 3) longitudinal design of study.

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Ethics Statement

The studies involving human participants were reviewed and approved by the ethical committee of the author's institution (submission ID: 202010291658_SyRk). Participants provided their informed consent to participate in this study.

Conflict of interest

We have no conflict of interest to disclose.

Data Availability Statement

The supporting materials and data supporting the conclusions of this manuscript are available on the OSF data repository (<https://osf.io/jgxz8/>).

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