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Parental autonomy support (AS) has an important positive influence on the development of children' s executive function (EF); interventions can improve parental AS, but its trajectory of change, influencing factors, and far-transfer effects on children' s EF remain unclear. This study recruited elementary school children and their parents to participate in an AS intervention experiment to examine these issues. The results showed that, compared with the control group (n = 80), parents in the intervention group (n = 79) showed a significant increase in AS at the posttest; the intervention effect emerged after the second intervention, gradually increased as the intervention progressed, and remained stable during the follow-up phase; the lower the baseline level of parental AS at the pretest, the better the intervention effect. Retrospective analysis revealed clear differences in AS change trajectories between the positive group (whose AS increased significantly after the intervention) and the negative group (whose AS decreased after the intervention). In addition, the effect of the AS intervention transferred to children' s everyday EF, but not to optimal EF, during the follow-up period, and this effect was influenced by baseline AS level. In sum, this study found that the intervention effect on parental AS and its far-transfer effect on children' s EF were influenced by baseline AS level.

Full Text

An Exploration of the Mechanisms by Which Parental Autonomy-Support Interventions Influence Children' s Executive Function

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Abstract

Parental autonomy support (autonomy support, AS) has an important positive influence on the development of children' s executive function (executive function, EF); interventions can improve parental AS, but its trajectory of change, influencing factors, and distal transfer effects on children' s EF remain unclear. This study recruited primary-school children and their parents to participate in an AS intervention experiment in order to examine the above questions. The results showed that, compared with the control group (n = 80), the intervention group (n = 79) showed a significant increase in parental AS at posttest; the intervention effect appeared significantly at the second intervention, increased

further as the intervention progressed, and remained stable during the follow-up stage; the lower the baseline level of parental AS at pretest, the better the intervention effect. Retrospective analysis found that the trajectories of change in AS differed significantly between the positive group (AS increased significantly after the intervention) and the negative group (AS decreased after the intervention). In addition, the effect of the AS intervention transferred during follow-up to children' s daily EF rather than optimal EF, and was influenced by the baseline level of AS. In sum, the study found that the intervention effect of parental AS and its distal transfer effect on children' s EF are influenced by the baseline level of AS.

Keywords parental autonomy support; children' s executive function; autonomy-support intervention; trajectory of change; transfer effect

1. Introduction

1.1 Children' s Executive Function and Parental Autonomy Support

Executive function (executive function, EF) skills are a set of neurocognitive skills that support individuals' conscious, top-down attentional control over thought, action, and emotion, including the capacity for bottom-up and top-down (reactive, automatic) and top-down (e.g., reflective, effortful) control (Zelazo, 2024). EF can be divided into three dimensions: inhibition, updating, and shifting.

(Miyake et al., 2000). The development of EF begins in late infancy and progresses rapidly during childhood and adolescence (Happaney & Zelazo, 2022). According to ecological systems theory, its development is influenced by the rearing environment (Frick, 2025), in which parental autonomy support (AS) has a unique role in EF development (Distefano & Meuwissen, 2022; Hanlin & Zhou, 2024; Koskulu-Sancar et al., 2023; Li et al., 2023; Zhang et al., 2026).

The concept of AS derives from three theories: separation–individuation theory, self-determination theory, and scaffolding theory (McCurdy et al., 2020). It includes the following components. First is emotional or relational support, such as following the child' s rhythm and creating a warm emotional atmosphere that gives the child encouragement and creativity (Regueiro et al., 2020). Second is cognitive or competence support, such as providing scaffolded support and guidance based on the child' s current level of ability and need, and adjusting task difficulty according to the child' s ability (Bernier et al., 2010; Hughes et al., 2009). Third is the transfer of responsibility and the provision of choices, that is, offering children limited choices and respecting their choices (Castelo et al., 2022). Some studies also include structured contexts within the scope of AS, such as setting clear expectations, consistent rules, and predictable consequences, to promote children' s ability to plan and organize their own behavior (Hughes et al., 2018; Grolnick et al., 2014; Mameli et al., 2025). The facilitative effect of AS on EF development is reflected in both task processes and subjective experience. In terms of task processes, AS helps children practice executive

skills from the bottom up within their zone of proximal development, including inhibiting prepotent responses and distracting stimuli, updating and focusing on task goals, and flexibly employing multiple problem-solving strategies (Baker, 2023; Zhang et al., 2026). In addition, AS also promotes the top-down development of children' s EF, such as reflection, planning, and effortful engagement (Hughes, 2013; Jiang et al., 2024). In terms of subjective experience, by giving respect and support, providing opportunities for choice, and acknowledging children' s perspectives, AS enables children to develop a sense of self-efficacy. This in turn motivates children to try novel and challenging tasks more actively and to continuously improve their EF skills and problem-solving abilities in these tasks (Carlson, 2023).

1.2 Problem Statement

The aforementioned studies have examined the influence of AS on EF in everyday contexts, but at present only very few studies have explored changes in children' s EF brought about by parental AS in intervention contexts (Tapia, 2023), and the findings are inconsistent (Lau et al., 2025). Existing studies have found that parents from high-risk families (such as foster parents) can benefit significantly from interventions and markedly enhance children' s EF development (Lind et al., 2017); however, the benefits obtained by parents from ordinary families in interventions do not show significant transfer effects on children' s EF (Day, 2022; Meuwissen & Carlson, 2019; O' lley et al., 2024; Tapia, 2023). For example, in the study by Day et al. (2024), they designed an eight-week parent-child play-based parental AS intervention and recruited 21 parent-child dyads to participate. The final results found that parental AS improved, but children' s EF did not change significantly. Tapia (2023) also found similar results: they implemented a three-session intervention for parents, aiming to help parents understand EF and to evaluate whether the training would affect children' s EF; however, this study found no significant changes in children' s EF before and after the parental intervention. In the study by Meuwissen and Carlson (2019), they manipulated the instructional language used in a puzzle task; in the AS group, parents were guided to use AS behaviors to 引

guide children in completing puzzle tasks; in the control group, parents were instructed to guide their children in completing puzzle tasks by using controlling behaviors.

The results showed that different manipulations changed parents' AS behaviors and induced changes in children' s self-regulation in subsequent tasks, but there was no change in children' s EF test performance. Even O' Illey' s (2024) meta-analysis found that parent-involved interventions had no effect on children' s EF. These intervention findings contradict existing cross-sectional and longitudinal research findings, which have reported a significant effect of parental AS on children' s EF (Distefano & Meuwissen, 2022). On the basis of this contradiction, the present study raises the following question: Can the benefits that parents obtain from AS interventions transfer to children's EF, and what factors

influence this?

First, according to several meta-analytic reports on the effects of interventions targeting parental AS, factors such as the intervention condition setting, parent characteristics, and child characteristics all influence the intervention effects parents obtain (Day, 2022; Grolnick et al., 2011; O' Illey et al., 2024; Su & Reeve, 2011; Wang et al., 2024). In terms of intervention setting, compared with short-term interventions (one to two sessions) and long-term interventions (eight sessions or more), medium-duration interventions (four to six sessions) are the most effective; training programs in which each intervention lasts 1 to 3 hours are relatively more effective; and, compared with family meetings and online interventions, intervention studies conducted in laboratory settings have more stable and stronger intervention effects (Su & Reeve, 2011). With respect to parent and child characteristics, families in which parents have lower levels of education and lower economic status, parents show lower baseline levels of AS at pretest, and children display more pronounced internalizing symptoms obtain better intervention effects after the intervention (Day, 2022; Grolnick et al., 2011; Meuwissen & Carlson, 2019). Although the above meta-analyses did not reveal whether parents' gains in AS interventions transfer to children' s executive functioning, it is worth continuing to explore in subsequent research whether the factors that influence intervention effects also influence transfer effects.

Second, according to recent discussions in the field concerning the development of children' s EF, some scholars hold that EF development is more context-dependent than previously assumed. Children' s EF originates from their goal-directed activities; specific goals activate psychological contents such as knowledge, beliefs, values, norms, interests, and preferences (Doebel & Müller, 2023; Holochwost et al., 2023; Ibbotson, 2023; Milosavljevic et al., 2024; Zelazo & Carlson, 2023). These elements, acquired in specific sociocultural contexts, affect the ways in which children implement control behaviors (Ibbotson, 2023; Frick & Chevalier, 2023). The real-time states described by this type of "dynamic systems theory" influence the nature of control and goal-directed behavior (Perone et al., 2021). When parents provide AS behaviors to children, they transmit their own, family-level, and even societal beliefs, values, norms, and interests to children (Zheng et al., 2026), and these contents change with specific contexts. Two recent studies reported that in different contexts (learning, play, or everyday-life contexts), parents' AS behaviors toward children differ, and these differences moderate the effect of parental AS on children' s EF (Huang et al., 2021; Zheng et al., 2026). For example, Zheng et al. (2026) found that, compared with parental AS in a general context, parental AS in an academic context had a stronger effect on the development of executive function in primary-school children. Thus, the particular context in which a parental AS intervention program is implemented may also influence the intervention effect and its transfer effect.

In selecting appropriate background or situational settings for parents' AS inter-

vention programs, it is necessary to fully consider the age of the children in the families receiving the intervention and their cultural backgrounds. On the one hand, at different stages of child development, parents' priorities in caring for children differ, which may lead them to display different levels of AS across different situations (Huang et al., 2021). On the other hand, cultural background also affects the psychological content—such as knowledge, beliefs, and values—that parents transmit when providing AS behaviors to children; children internalize these culturally specific forms of knowledge and beliefs and use them to guide their own behavior (Ibbotson, 2023). Therefore, the cultural background of families receiving the intervention and children' s age directly influence the design of parental AS intervention programs, and become potential factors affecting intervention effects and transfer effects.

1.3 Research Rationale

Based on the above research background, this study focuses on three questions: (1) whether the intervention effects obtained by parents through an intervention on parental AS can transfer to children' s EF; (2) what factors influence the intervention and transfer effects; and (3) what the intervention and transfer processes and potential mechanisms are.

Because Huang et al. (2021) and Zheng et al. (2026) explored differences in parental AS across different situations using Chinese children and their parents as participants, and found that parents' AS level was highest in academic contexts and had a greater impact on children' s EF, the researchers believed that this result partly reflected the characteristics of Chinese parents, who value children' s learning, are willing to invest emotional and cognitive support, and promote children' s development of independent learning habits (Huang et al., 2021; Zheng et al., 2026). These characteristics may help children show better planning-control behaviors when solving problems in the learning domain, thereby promoting EF development (Doebel & Müller, 2023; Frick & Chevalier, 2023; Ibbotson, 2023). Therefore, this study argues that designing parental AS intervention programs based on academic contexts is more consistent with our real-world background.

Furthermore, this study selected primary-school children and their parents as research participants. Learning is the main activity of children at the primary-school stage, and it is also a key focus of parental concern at this stage. Compared with daily affairs management, parents invest a great deal of time in supervising, guiding, and planning their children' s learning (Brumariu & Kerns, 2022; Ng & Wei, 2020). Children at this stage also need good EF to support improvements in their learning skills and adaptive abilities (Van Tetering et al., 2022). Therefore, through an autonomy-support intervention based on academic contexts, parents can enhance their AS skills, which may in turn promote children' s EF development and improve children' s adaptive abilities. Based on the above reasons, we believe that it is appropriate to use primary-school children and their parents as research participants.

In addition, this study also selected three variables—parents' education level, income, and baseline level of parental AS—to examine whether the intervention effects and transfer effects obtained by parents would be influenced by potential factors. Existing meta-analyses have found that intervention condition settings and parental characteristics affect parents' gains from interventions (Day, 2022; Grolnick et al., 2011; O' Reilly, 2025; Su & Reeve, 2011); however, the former may only influence the external form of the intervention and cannot determine its intrinsic essence,

the latter may be an intrinsic mechanism that influences the intervention. Therefore, this study includes variables related to parental characteristics within the scope of the investigation, examining the influence of parents' personal characteristics on the potential mechanisms of the intervention.

In summary, this study will investigate, among primary-school children, the intervention effect of parent AS based on academic contexts, its transfer effect on children' s EF and the change trajectories of both, as well as the influence of parents' educational level and income, and baseline level of parent AS. First, this study will track the trajectories of change in parent AS levels before, during, and after the intervention, in order to evaluate the intervention effect and the process of change. Next, by comparing changes in children's EF before and after the intervention and analyzing the influence of changes in parent AS before and after the intervention on changes in children' s EF, it will evaluate whether the intervention effects obtained by parents can transfer to children's EF and explore the process of such change. Finally, this study will also analyze the influence of parents' educational level and baseline parent AS level on the intervention effect and transfer effect. This study hypothesizes that an academic-context-based intervention on parent AS will effectively increase parent AS behaviors and will also transfer to children's EF; however, the intervention effect and transfer effect will be influenced by parents' educational level and baseline AS level.

2. Methods

2.1 Participants and Participation Procedure

Parents of 159 students in Grades 1 to 3 from three schools in a city in western China, together with their children, were recruited to participate in this study. All participating parents signed informed-consent forms and confidentiality agreements to ensure that the study complied with ethical standards. After random assignment, 82 parents and their children were recruited into each of the intervention and control groups; for the demographic information of the two groups, see Table 1.

In the intervention group, parents were randomly assigned to four parallel subgroups and participated in an offline intervention course once per week, 2 hours each time. The specific procedure (Table 2) was as follows: (1) at pretest, parents completed the relevant online questionnaire survey; (2) after the intervention began, parents came to the laboratory to receive the intervention; (3)

3–4 days after the end of the first, second, and third intervention sessions, parents completed the Academic Autonomous Support Questionnaire online; these several assessments were midtests 1–3; (4) within 3–4 days after the end of the fourth intervention session, parents completed the relevant online questionnaire survey, which served as the posttest; (5) in the first and second months after the end of the intervention, parents completed two online questionnaire assessments, namely follow-up tests 1 and 2; (6) after follow-up test 2, parents and children came together to the laboratory again; parents participated in a parent activity organized by the research team, while children completed the EF task; (7) children in the intervention group completed the EF task at pretest, posttest, and follow-up test 2, all in an independent room at their school, accompanied one-on-one by a research assistant. During implementation of the intervention, 11 parents withdrew for personal reasons after the first intervention session; in the subsequent sessions, 2, 1, and 10 parents withdrew, respectively. During the two follow-up assessments after the end of the intervention, another 4 parents withdrew. Ultimately, complete follow-up data were obtained from 54 parents in the intervention group and their children (65.85%).

The specific procedure for the control group (Table 2) was as follows: at pretest, parents completed the relevant questionnaire survey online; one week after the pretest, parents in this group were sent a popular-science article of about 2,000 Chinese characters concerning parent AS every week, and completed a brief questionnaire to ensure that parents ···

reading for four consecutive weeks. At 3–4 days after the four-week essay-reading period ended, the posttest was initiated, at which time parents again completed the relevant questionnaires online. At both pretest and posttest, all 80 parents completed all questionnaire measures. Children in the control group completed the EF tasks one-on-one with an experimenter in an independent room at their school at both pretest and posttest.

The above experimental procedures were approved by the ethics committee of the authors' institution (H24106).

Table 1. Demographic information for the control group and intervention group

Variable	Category	Intervention group	Control group
Child gender	Male	44 (55.7%)	49 (56.3%)
Child gender	Female	35 (44.3%)	38 (43.7%)
Child age	$M \pm SD$	7.595 ± 0.927 years	7.170 ± 1.076 years
Child grade	Grade 1	48 (60.8%)	41 (47.1%)
Child grade	Grade 2	14 (17.7%)	9 (10.4%)
Child grade	Grade 3	17 (21.5%)	37 (42.5%)
Parent gender	Father	14 (17.7%)	10 (11.5%)
Parent gender	Mother	65 (82.3%)	77 (88.5%)
Parent age	$M \pm SD$	37.980 ± 4.050 years	37.800 ± 4.952 years

Variable	Category	Intervention group	Control group
Parents' educational level	Junior high school	2 (2.5%)	10 (11.5%)
Parents' educational level	Senior high school	8 (10.1%)	22 (25.3%)
Parents' educational level	Junior college	15 (19.0%)	20 (23.0%)
Parents' educational level	Bachelor' s degree	40 (50.7%)	33 (37.9%)
Parents' educational level	Master' s degree or above	14 (17.7%)	2 (2.3%)
Monthly household income	1-5000 yuan	1 (1.3%)	6 (6.9%)
Monthly household income	5001-10000 yuan	14 (17.7%)	33 (37.9%)
Monthly household income	10001-15000 yuan	19 (24.1%)	23 (26.4%)
Monthly household income	15001-20000 yuan	22 (27.8%)	13 (15.0%)
Monthly household income	More than 20000 yuan	23 (29.1%)	12 (13.8%)

2.2 Research Instruments

Parental autonomy support. Parental academic autonomy support was measured using the Parental Academic Autonomy Support Scale (Zheng et al., 2026). The scale contains 12 items and uses a 5-point Likert scoring method (1 = strongly disagree; 5 = strongly agree). Scores for each dimension are obtained by averaging the scores of the corresponding items; higher scores indicate a higher level of parental academic autonomy support. The scale contains four dimensions: emotional support, responsibility transfer, cognitive support, and structural rules. In the present study, the Cronbach' s α coefficient of this scale was 0.944.

Children' s EF. Children' s everyday EF (typical EF) and optimal EF were

collected. The instrument used to assess the former was the school-age child Behavior Rating Inventory of Executive Function (BRIEF) scale rated by parents (Qian

& Wang, 2007); it contains 86 items and uses a Likert 3-point scoring method (1 = never; 2 = sometimes; 3 = often). The total score is the average score of the items under each dimension; higher scores indicate more severe impairment in children's everyday executive-function performance. The scale contains 8 factors, which belong respectively to two composite indices: the Behavioral Regulation Index (BRI) and the Metacognition Index (MI) (Roth & Gioia, 2005). In the present study, the Cronbach' s α coefficient of this scale was 0.971. The optimal EF testing tool was the Dimensional Change Card Sort Task (DCCS) (Zelazo, 2006). The experimental materials included two target cards displayed in the upper area of the screen (a blue rabbit and a red boat) and the cards to be classified in the lower area of the screen. The task included three classification rules: the color-classification rule required participants to classify the cards by color (blue and red); the shape-classification rule required participants to classify them by shape (rabbit and boat shapes); and the switch-classification rule required participants to select the classification rule according to whether the card had a black border—classifying by color when there was a black border, and by shape when there was no black border. The experiment included two phases: practice and formal testing. In the practice phase, participants were required to complete practice trials for the color-classification, shape-classification, and switch-classification tasks in sequence, and could enter the formal experiment only after reaching an accuracy rate of 70%. In the formal switching-task phase, after every 3–4 consecutive classifications, the classification rule changed. In the formal experimental phase, there were 30 rule switches and 105 classifications in total. Accuracy and reaction time in the switching task were used as evaluation indicators (Zelazo, 2006).

Demographic questionnaire. Information was collected on children's gender, grade, and age, as well as parents' age range, educational level, and monthly household income.

2.3 Intervention Program

In parent–child interactions, parents with lower AS are often more inclined to be controlling and intrusive (Spruijt et al., 2018), which may lead to more poor communication and parent–child conflict. Therefore, this intervention began with parent–child conflict in the academic context. By guiding parents to become aware of the control, intrusion, and negative effects they exert during conflict, it explained the connotations and positive effects of AS, and provided AS behavioral strategies and practical exercises. The intervention was conducted four times in total (once per week, 2 hours each time). The specific content of the intervention is shown in Appendix Table 1.

2.4 Data Analysis

This study used SPSS 25.0 to process and analyze the data, including descriptive statistics, correlation analysis, repeated-measures analysis of variance, cluster analysis, and regression analysis.

3. Research Results

3.1 Analysis of Intervention Effects

A four-group 2 (group: intervention group, control group) × 2 (time: pretest, posttest) repeated-measures analysis of variance was used to analyze

Changes in parent AS and child EF in the intervention group and the control group before and after the intervention (Figure 1 and Table 3).

With parent AS as the dependent variable: the main effect of group was not significant ($F[1, 132] = 2.891, p = 0.092, \eta^2 = 0.029$), the main effect of time was not significant ($F[1, 132] = 3.882, p = 0.06, \eta^2 = 0.032$), and the interaction was significant ($F[1, 132] = 6.58, p = 0.011, \eta^2 = 0.06$). Further simple-effects analyses showed that parent AS in the intervention group was significantly higher at posttest than at pretest ($F[1, 132] = 10.011, p = 0.002, \eta^2 = 0.081$), whereas the pretest–posttest difference in parent AS in the control group was not significant ($F[1, 132] = 0.182, p = 0.671, \eta^2 = 0.002$). The results indicate that the intervention can effectively improve parents' level of academic autonomy support.

With children' s BRIEF score, DCCS task accuracy, and reaction time as dependent variables: the main effect of group was not significant (BRIEF: $F[1, 132] = 2.432, p = 0.122, \eta^2 = 0.022$; DCCS accuracy: $F[1, 132] = 3.527, p = 0.063, \eta^2 = 0.023$; DCCS reaction time: $F[1, 132] = 1.351, p = 0.247, \eta^2 = 0.011$); the main effect of time was not significant (BRIEF: $F[1, 132] = 0.09, p = 0.769, \eta^2 = 0.001$; DCCS accuracy: $F[1, 132] = 0.379, p = 0.539, \eta^2 = 0.003$; DCCS reaction time: $F[1, 132] = 1.432, p = 0.256, \eta^2 = 0.01$); and the interaction was not significant (BRIEF: $F[1, 132] = 0.27, p = 0.608, \eta^2 = 0.002$; DCCS accuracy: $F[1, 132] = 0.379, p = 0.651, \eta^2 = 0.002$; DCCS reaction time: $F[1, 132] = 0.611, p = 0.436, \eta^2 = 0.005$). The accuracy and reaction time of the BRIEF and DCCS tasks represent children' s everyday EF and optimal EF, respectively. Accordingly, the results of this group indicate that the intervention effect of parent AS did not transfer at posttest to children' s everyday EF or optimal EF.

Table 3. Means (M) and standard deviations (SD) of each variable at each measurement time point in the control group and intervention group

Group	Test point	AS (M/SD)	BRIEF (M/SD)	DCCS accuracy (M/SD)	DCCS reaction time (M/SD)
Control group	Pretest	3.488/0.494	1.634/0.261	77.06%/0.121	653.741/267.236
Control group	Posttest	3.456/0.662	1.653/0.270	77.31%/0.115	642.613/218.504
Intervention group	Pretest	3.515/0.586	1.736/0.396	78.98%/0.124	635.739/269.678
Intervention group	Midtest 1	3.654/0.646	–	–	–
Intervention group	Midtest 2	3.789/0.628	–	–	–
Intervention group	Midtest 3	3.826/0.582	–	–	–
Intervention group	Posttest	3.758/0.574	1.731/0.363	80.65%/0.114	623.933/220.707
Intervention group	Follow-up 1	3.770/0.573	1.723/0.394	–	–
Intervention group	Follow-up 2	3.799/0.551	1.656/0.400	77.69%/0.112	611.392/220.161
Intervention group	Δ Posttest–Pretest	0.242/0.510	-0.005/0.227	–	–
Intervention group	Δ Follow-up 1–Pretest	0.255/0.545	-0.013/0.219	–	–
Intervention group	Δ Follow-up 2–Pretest	0.284/0.480	-0.080/0.207	–	–

Table 2. Flowchart of Experimental Implementation for the Intervention Group and Control Group

Figure 1. Comparison of parental AS and children' s EF between the control group and the intervention group before and after the intervention

Figure 1: Figure 1. Comparison of parental AS and children' s EF between the control group and the intervention group before and after the intervention

	Pretest	Intervention 1	Mid-test 1	Intervention 2	Mid-test 2	Intervention 3	Mid-test 3	Intervention 4	Post-test	Follow-up Test 1	Follow-up Test 2	Meeting
	One week before intervention	Week 1	3–4 days after the 1st intervention	Week 2	3–4 days after the 2nd intervention	Week 3	3–4 days after the 3rd intervention	Week 4	3–4 days after the 4th intervention	1 month after completion	2 months after completion	One week after Follow-up Test 2
Intervention group	**Parents:** Demographic questionnaire / AS / BRIEF; **Children:** DCCS	Parents: intervention	Parents: AS questionnaire	Parents: intervention	Parents: AS questionnaire	Parents: intervention	Parents: AS questionnaire	Parents: intervention	**Parents:** Demographic questionnaire / AS / BRIEF; **Children:** DCCS	Parents: AS, BRIEF questionnaires	Parents: AS, BRIEF questionnaires	Children: DCCS
Control group	**Children:** DCCS	Popular science article	Popular science article	Popular science article	Popular science article	Popular science article	Popular science article	Popular science article	**Children:** DCCS	—	—	—

Figure 1. Comparison of parental AS and children' s EF between the control group and the intervention group before and after the intervention

3.2 Process changes in parental AS and children's executive function in the intervention group

Figure 2a shows the changing trend of parental AS in the intervention group across the seven measurements: pretest, midtests 1–3, posttest, and follow-up tests 1–2. Overall, parental AS showed an upward trend. A one-way repeated-measures method was used to analyze changes in parental AS. First, the Mauchly test of sphericity showed that the data met the sphericity assumption ($\chi^2[20] = 30.021, p = 0.069$), satisfying the applicability conditions for repeated-measures analysis of variance. The repeated-measures ANOVA then showed that the main effect of measurement time was significant ($F[6, 318] = 6.173, p < 0.001, \eta^2 = 0.101$), indicating that parental AS differed significantly across measurement time points. Paired comparisons (Bonferroni correction) found that parental AS at pretest differed significantly from parental AS at midtests 2 and 3 and follow-up tests 1 and 2; follow-up test 1 differed significantly from midtest 2, midtest 3, and follow-up test 3 ($p < 0.01$) (Table 3 and Appendix Table 2). In summary, the intervention effect appeared after the second session, improved further as the course progressed, and remained stable during the follow-up phase.

Figure 2b shows the changing trend of the intervention-group children' s BRIEF scores across the four measurements: pretest, posttest, and follow-up tests 1 and 2. A one-way repeated-measures method was used to analyze changes in children' s typical EF. The Mauchly test of sphericity showed that the data met the sphericity assumption ($\chi^2[6] = 3.781, p = 0.706$). The repeated-measures ANOVA showed that the main effect of time was significant ($F[3, 159] = 3.142, p = 0.027, \eta^2 = 0.061$). Paired comparisons (Bonferroni correction) found that children' s daily EF at follow-up test 2 was significantly lower than at pretest, posttest, and follow-up test 1 ($p < 0.01$) (Table 3 and Appendix Table 2). Because lower BRIEF scores indicate better children's daily EF, these results suggest that the short-term effect of the parent-classroom intervention on children' s daily EF was not significant, but its long-term effect was significant.

Figures 2c and 3d respectively show the accuracy and reaction time of the intervention-group children on the DCCS task at pretest, posttest, and follow-up 2.

changes across the three measurements. A one-factor repeated-measures method was used to analyze changes in children' s accuracy and reaction time on the DCCS task. The Mauchly sphericity test results showed that the data met the sphericity assumption ($\chi^2[2] = 0.918/2.561$, $p = 0.632/0.279$). Repeated-measures ANOVA showed that the main effect of time was not significant ($F[2, 106] = 0.791/1.171$, $p = 0.457/0.314$, $\eta^2 = 0.015/0.022$). Accordingly, the results of this study indicate that the short-term and long-term effects of the intervention on children' s optimal EF were not significant.

Figure 2. Comparison of changes in mothers' AS and children' s EF across measurement time points in the intervention group

Figure 2: Comparison of changes in mothers' AS and children' s EF across measurement time points in the intervention group. Panels: a, AS; b, BRIEF; c, DCCS accuracy; d, DCCS reaction time.

Figure 2: Figure 2: Comparison of changes in mothers' AS and children' s EF across measurement time points in the intervention group. Panels: a, AS; b, BRIEF; c, DCCS accuracy; d, DCCS reaction time.

3.3 Relationship between Changes in Parental AS Before and After the Intervention and Changes in Children' s Executive Function

Using the pretest levels of parental AS and children' s daily EF as baselines, the differences between posttest, follow-up test 1, and follow-up test 2 and the baseline level were calculated, in order to reflect changes in parental AS and children' s EF before and after the intervention (the change scores were respectively: $\Delta AS_{\text{posttest-pretest}}$, $\Delta AS_{\text{follow-up 1-pretest}}$, $\Delta AS_{\text{follow-up 2-pretest}}$, $\Delta EF_{\text{posttest-pretest}}$, $\Delta EF_{\text{follow-up 1-pretest}}$, $\Delta EF_{\text{follow-up 2-pretest}}$); correlations between children' s gender, grade, parents' education level and family income, and the change scores of AS and EF were then calculated (Table 4). Because the differences between pretest, posttest, and follow-up tests for children' s optimal EF were not significant, they were not included in subsequent analyses.

Four main sets of results were obtained: (1) Parents' education level was significantly negatively correlated with the EF pretest and with $\Delta AS_{\text{follow-up 1-pretest}}$ ($r = -0.309^{*} / -0.333^{*}$, $p < 0.001$), and was significantly positively correlated with $\Delta EF_{\text{follow-up 2-pretest}}$ ($r = 0.302^{*}$, $p < 0.001$), indicating that higher parental education level was associated with better child EF and with better changes in AS and EF. (2) AS_{pretest} was significantly negatively correlated with $\Delta AS_{\text{posttest-pretest}}$, $\Delta AS_{\text{follow-up 1-pretest}}$, and $\Delta AS_{\text{follow-up 2-pretest}}$ ($r = -0.49 \sim -0.46$, $p < 0.001$), and $\Delta AS_{\text{posttest-pretest}}$, $\Delta AS_{\text{follow-up 1-pretest}}$, and $\Delta AS_{\text{follow-up 2-pretest}}$ were positively correlated with one another in pairs ($r = 0.69 \sim 0.75$, $p < 0.001$), indicating that when parents' AS at pretest was lower, the post-intervention change was greater, and changes in parental AS at different time points showed relatively high consistency. (3) EF_{pretest} was significantly negatively correlated with $\Delta EF_{\text{posttest-pretest}}$, $\Delta EF_{\text{follow-up 1-pretest}}$, and $\Delta EF_{\text{follow-up 2-pretest}}$ ($r = -0.43 \sim -0.29$, $p = 0.036 \sim 0.001$), and $\Delta EF_{\text{posttest-pretest}}$, $\Delta EF_{\text{follow-up 1-pretest}}$, and $\Delta EF_{\text{follow-up 2-pretest}}$ were positively correlated with one another in pairs ($r = 0.41 \sim 0.59$, $p < 0.001$), indicating that when children' s daily EF at pretest was lower (a higher scale score), the post-intervention change was greater, and children' s typical EF at different time points showed relatively high consistency.

consistency. (4) $\Delta AS_{\text{posttest-pretest}}$, $\Delta AS_{\text{follow-up 1-pretest}}$, and $\Delta AS_{\text{follow-up 2-pretest}}$ were all significantly negatively correlated with $\Delta EF_{\text{posttest-pretest}}$, $\Delta EF_{\text{follow-up 1-pretest}}$, and $\Delta EF_{\text{follow-up 2-pretest}}$ (all pairwise; $r = -0.43 \sim -0.28$, $p = 0.044 \sim 0.001$),

Figure 3. Dendrogram and scatterplot of the cluster analysis

Figure 3: Figure 3. Dendrogram and scatterplot of the cluster analysis

indicating that the greater the change in parents' AS after the intervention, the greater the change in children' s EF. In addition, the correlations among the remaining variables were not significant.

Next, three sets of hierarchical regressions were conducted to further examine the relationships among the above variables. Using $\Delta EF_{\text{posttest-pretest}}/\Delta EF_{\text{follow-up 1-pretest}}/\Delta EF_{\text{follow-up 2-pretes}}$ respectively as dependent variables, children' s grade and parents' educational level as first-level independent variables, and $\Delta AS_{\text{posttest-pretest}}/\Delta AS_{\text{follow-up 1-pretest}}/\Delta AS_{\text{follow-up 2-pretest}}$ as second-level newly added independent variables, three regression analysis equations were constructed. The results showed that the first-level regression equations of the three regression analyses were all non-significant ($F[2, 51] = 0.335 \sim 1.863$, $p = 0.166 \sim 0.717$). When $\Delta EF_{\text{posttest-pretest}}/\Delta EF_{\text{follow-up 1-pretest}}$ were used as dependent variables and $\Delta AS_{\text{posttest-pretest}}/\Delta AS_{\text{follow-up 1-pretest}}$ entered the regression equations as second-level newly added independent variables, the regression equations were significant ($F[1, 51] = 2.873/3.731$, $p = 0.045/0.017$), and the newly added independent variables significantly predicted the dependent variables ($t[51] = -2.298/-3.225$, $p = 0.026/0.002$). When $\Delta EF_{\text{follow-up 2-pretest}}$ was used as the dependent variable and $\Delta AS_{\text{follow-up 2-pretest}}$ entered the regression equation as the second-level newly added independent variable, the regression equation was not significant ($F[1, 51] = 1.554$, $p = 0.212$) (Table 5).

3.4 Effects of Positive and Negative Changes in Parents' AS Intervention on Changes in Children' s EF

Because the correlation analysis results showed that the effect of the parents' AS intervention had a moderate and significant correlation with changes in children' s EF, in order to further clarify how the parents' AS intervention effect would influence the trajectory of changes in children' s EF, this study first used cluster analysis to group the intervention effects of parents' AS, and then used repeated-measures analysis of variance to examine the trajectories of changes in parents' AS and children' s EF in each group. The details are as follows:

(1) Hierarchical cluster analysis was used to group participants in the intervention group based on $\Delta AS_{\text{follow-up 2-pretest}}$. According to the classification results, the intervention effects could be divided into a positive-change group (at the last follow-up test, parents' AS remained stable or increased after the intervention compared with the pretest) and a negative-change group (at the last follow-up test, parents' AS decreased after the intervention compared with the pretest). The positive-change group included 41 participants, and the negative-change group included 13 participants (Figure 3). The descriptive statistical results for the two groups are shown in Table 6.

Figure 3. Dendrogram and scatterplot of the cluster analysis

Table 4. Correlations among demographic variables, parental AS, children' s EF, and their change scores

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Child gender	–																	
2 Child grade	-0.030	–																
3 Parental educational level	0.175***	0.065	–															
4 Monthly household income	-0.011	0.038	0.324***	–														
5 AS pretest	0.021	0.210***	0.182***	0.007	–													
6 AS posttest	0.073	0.101*	0.051	0.076	0.613***	–												
7 AS follow-up test 1	0.187***	0.017	-0.070	-0.054	0.557***	0.782***	–											
8 AS follow-up test 2	0.049	-0.066	-0.037	-0.010	0.640***	0.755***	0.762***	–										

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
9 EF pretest	- 0.204	0.028 0.309*	- 0.046	- 0.287*	-	0.008	0.039 0.189	-	–									
10 EF posttest	- 0.168	0.128 0.249	- 0.018	- 0.218	- 0.088	-	0.006 0.182	-	0.824***									
11 EF follow-up test 1	- 0.243	0.051 0.267	- 0.084	- 0.294*	- 0.196	-	- 0.192	- 0.302*	0.847***	0.799***								
12 EF follow-up test 2	- 0.214	0.102 0.204	- 0.011	- 0.262	- 0.096	-	- 0.078	- 0.257	0.865***	0.825***	0.883***							
13 ΔAS posttest–pretest	0.121 0.110	- 0.254	-	0.129 0.458***	-	0.421**	0.241	0.110	0.338*	0.152	0.116	0.193	–					
14 ΔAS follow-up test 1–pretest	- 0.165	- 0.168	- 0.333*	0.121 0.489***	-	0.163	0.452**	0.108	0.349**	0.241	0.114	0.200	0.745***	–				
15 ΔAS follow-up test 2–pretest	0.045 0.337*	- 0.201	-	- 0.019	-	0.118	0.194 0.481***	0.361**	0.133	0.058	0.013	0.025	0.685***	0.720***	–			
16 ΔEF posttest–pretest	0.093	0.148	0.176	0.061	0.151	- 0.155	- 0.059	0.039 0.428**	- 0.159 0.202	-	- 0.191	-	- 0.348**	- 0.224	- 0.139	–		

Variable	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
17 - ΔEF follow-up test 1–pretest	0.053	0.156	0.011	-0.010	-0.369	-0.416**	-0.201	-0.286*	-0.053	0.268	0.024	-0.403**	-0.426**	-0.218	0.413**		
18 - ΔEF follow-up test 2–pretest	0.155	0.302*	0.164	0.042	-0.201	-0.225	-0.135	-0.242	0.018	0.086	0.277*	-0.275*	-0.282*	-0.287*	0.450**	0.593***	

Note: * indicates $P < 0.05$, ** indicates $P < 0.01$, *** indicates $P < 0.001$.

Table 5. Regression Analysis of the Intervention Group

Item		β	t	P	R^2	ΔR^2	F	P
Dependent variable: ΔEF posttest–pretest								
First level	Constant		-1.677	0.100	0.057	0.057	1.539	0.224
	Child grade	0.165	1.215	0.230				
	Parental education level	0.162	1.186	0.241				
Second level	Constant		-1.059	0.295	0.147	0.090	2.873	0.045
	Child grade	0.140	1.069	0.290				

Item		β	t	P	R^2	ΔR^2	F	P
	Parental education level	0.079	0.582	0.563				
	ΔAS posttest–pretest	-0.313	-2.298	0.026				
Dependent variable: ΔEF follow-up 1–pretest								
First level	Constant		-0.781	0.439	0.013	0.013	0.335	0.717
	Child grade	0.030	0.216	0.830				
	Parental education level	0.108	0.774	0.443				
Second level	Constant		0.287	0.775	0.183	0.170	3.731	0.017
	Child grade	-0.025	-0.197	0.845				
	Parental-education level	-0.029	-0.218	0.828				
	ΔAS follow-up 1–pretest	-0.439	-3.225	0.002				

Item		β	t	P	R^2	ΔR^2	F	P
Dependent variable: ΔEF follow-up 2-pretest								
First level	Constant		-1.899	0.063	0.068	0.068	1.863	0.166
	Child grade	0.116	0.856	0.396				
	Parental education level	0.227	1.673	0.101				
Second level	Constant		-1.473	0.147	0.085	0.017	1.554	0.212
	Child grade	0.077	0.542	0.590				
	Parental education level	0.198	1.427	0.160				
	ΔAS follow-up 2-pretest	-0.140	-0.969	0.337				

Table 6. Means (M) and Standard Deviations (SD) of AS and EF at Each Measurement Time Point for the Positive-Change Group and Negative-Change Group

Measurement time point	Group	Parental AS M	Parental AS SD	Child EF M	Child EF SD
Pretest	Positive-change group	3.338	0.537	1.752	0.410

Measurement time point	Group	Parental AS M	Parental AS SD	Child EF M	Child EF SD
Pretest	Negative-change group	3.870	0.525	1.704	0.376
Posttest	Positive-change group	3.789	0.491	1.744	0.379
Posttest	Negative-change group	3.694	0.724	1.705	0.337
Follow-up 1	Positive-change group	3.794	0.541	1.707	0.413
Follow-up 1	Negative-change group	3.722	0.645	1.756	0.363
Follow-up 2	Positive-change group	3.887	0.561	1.659	0.422
Follow-up 2	Negative-change group	3.625	0.499	1.650	0.365

(2) A 2 (group: positive group, negative group) × 4 (measurement time point: pretest, posttest, follow-up 1, follow-up 2) was adopted.

repeated-measures analysis of variance was used to compare parental AS and children' s EF across different measurement time points in the different groups.

With parental AS as the dependent variable, the repeated-measures ANOVA results showed that the main effect of group was not significant ($F[1, 156] = 0.03, p = 0.86, \eta^2 = 0.001$), the main effect of measurement time point was significant ($F[3, 156] = 4.15, p = 0.007, \eta^2 = 0.20$), and the interaction between group and measurement time point was significant ($F[3, 156] = 28.76, p < 0.001, \eta^2 = 0.63$). Simple-effects analyses found that the positive-change group had significantly lower pretest parental AS scores than the negative-change group ($t[52] = -3.459, p = 0.001$), whereas at the subsequent posttest, follow-up 1, and follow-up 2, there were no significant differences between the two groups ($t[52] = 0.569/0.431/1.674, p = 0.572/0.669/0.1$). In addition, the positive-change group' s scores at the posttest, follow-up test 1, and follow-up test 2 were significantly higher than at the pretest (Bonferroni-Holm corrected paired analyses; see Appendix Table 3), indicating that the intervention had a significant positive effect on parental AS for participants in this group, and that parental AS in the positive-change group showed an overall marked upward

Figure 4. Comparison of parental AS and children' s daily EF at each testing time point between the positive-change group and the negative-change group

Figure 4: Figure 4. Comparison of parental AS and children' s daily EF at each testing time point between the positive-change group and the negative-change group

trend (Figure 4). However, the negative-change group' s parental AS score at follow-up 2 was significantly lower than at the pretest (Appendix Table 3), showing an overall downward trend, indicating that for participants in this group, the intervention not only failed to produce the expected positive effect but may even have had a negative impact on parental AS.

Figure 4. Comparison of parental AS and children' s daily EF at each testing time point between the positive-change group and the negative-change group

With children' s BRIEF as the dependent variable, the repeated-measures ANOVA results showed that the main effect of group was not significant ($F[1, 156] = 0.01, p = 0.911, \eta^2 = 0.001$), the main effect of measurement time point was significant ($F[3, 156] = 2.70, p = 0.048, \eta^2 = 0.05$), and the interaction between group and measurement time point was not significant ($F[3, 156] = 0.95, p = 0.421, \eta^2 = 0.02$). Post hoc analyses found (Bonferroni-Holm comparisons) that the BRIEF scores of the positive-change group declined continuously from the pretest, to the posttest, to follow-up 1 and follow-up 2; the BRIEF score at follow-up 2 was significantly lower than those at the pretest and posttest (Appendix Table 3), but did not differ significantly from follow-up 1 (Figure 4). In the negative-change group, BRIEF scores did not differ significantly among the pretest, posttest, follow-up 1, and follow-up 2 (Appendix Table 3). This indicates that the intervention had a significant and positive effect on children' s executive function in the positive-change group, but its effect in the negative-change group was not evident.

Overall, the intervention effects differed across groups. For the positive-change group, the intervention effectively improved parental AS and promoted improvements in children' s daily EF; however, for the negative-change group, the intervention led to a decline in parental AS, and children' s daily EF showed no significant overall change.

4. Discussion

This study examined, in the context of academic work, the intervention effect on parents' AS, the transfer effect on children' s EF, and the trajectories of change in both, as well as the influence of parents' demographic variables and parents' baseline AS levels. The study found that after the intervention, parents' AS improved and the intervention effect was maintained, but the intervention effect was negatively related to parents' baseline AS level. The intervention effect on

parents'AS was significantly positively correlated with changes in children's daily EF. When parents' AS improved from before to after the intervention, children' s EF also improved; however, when parents' AS weakened from before to after the intervention, children' s EF showed no obvious change. To further explore the intervention effect, this study will discuss it from the following multiple perspectives.

4.1 The Influence of the Intervention on Parents' Autonomy Support

One of the key questions explored in this study was what the trajectory of parents' AS changes was before/during/after the intervention, and which factors it would be affected by. Based on current research findings, we will discuss this issue from the following aspects.

First, by collecting and comparing parents' AS at seven time points before, during, and after the intervention, this study found that after the first intervention ended, parents' level of academic autonomy support increased, but did not reach a significant level; as the course content gradually deepened, parents' AS increased significantly after the second and third courses ended; however, parents' AS decreased slightly at the posttest; but during the follow-up phase, parents' AS continued to maintain a stable and significant improvement. The above trajectory of change indicates that the intervention could effectively improve parents' AS, which is consistent with previous findings (Day, 2022; Grolnick et al., 2011; Meuwissen & Carlson, 2019; Su & Reeve, 2011). Going further than previous studies, the trajectory of change also revealed that the intervention effect had a certain cumulative nature: through repeated learning, practice, and feedback, parents could gradually master AS strategies and concepts; even after the intervention ended, the AS strategies and concepts acquired by parents could continue to be applied in real family educational contexts, and might even gradually be transformed into relatively stable parenting behaviors. However, the trajectory of change also showed that parents' AS did not increase continuously. Parents' AS declined slightly at the posttest when the intervention ended, although not significantly; this change was also replicated in a recent parent intervention project by this research group. The authors believe that this may be due to separation anxiety; that is, the end of the intervention may lead parents to worry about whether they have made sufficient progress, thereby lowering their evaluation of their own AS level. However, this needs to be further explored in subsequent research.

Furthermore, this study analyzed two types of factors influencing the intervention effect on parents' AS: parents' baseline AS level and parents' demographic variables. On the one hand, based on comprehensive correlation analyses and regression analyses, this study did not provide supportive evidence that parents' educational level and family economic income, two demographic variables, influenced the intervention effect on parents' AS or the transfer effect on children' s EF; this is inconsistent with previous studies (Day, 2022; Grolnick et al., 2011; Meuwissen & Carlson, 2019; Su & Reeve, 2011). On the other hand, the results

showed that the lower parents' AS baseline level at the pretest was, the greater the amount of change in parents' AS at the posttest and at each follow-up assessment; this is consistent with previous studies (Grolnick et al., 2021; Meuwissen &

Carlson, 2019). Subsequently, this study found that not all parents showed increased AS after the intervention; for some parents, AS instead decreased. This phenomenon is a new finding and has not been reported in previous studies. To further explore the reasons for this, the present study used cluster analysis to divide the amount of change in parents' autonomy support before and after the intervention into two groups: a positive group and a negative group, representing, respectively, increases and decreases in parents' AS after the intervention. Repeated-measures analyses of the two groups showed that parents' AS in the positive group was significantly lower than that in the negative group at pretest, but at posttest, follow-up 1, and follow-up 2, parents' AS in the positive group rose steadily; whereas parents' AS in the negative group continued to decline as the intervention proceeded, and by follow-up 2 parents' AS was significantly lower than at pretest. However, the differences in parents' AS between the two groups at posttest, follow-up 1, and follow-up 2 were all nonsignificant. This result first confirms that the baseline level of parents' AS affects their benefits from the intervention; second, it also suggests that during intervention we should pay more attention to parents with high baseline levels of AS. In daily life, they may have overestimated their own level of AS, and after receiving the intervention they may discover that what they previously believed to be AS behaviors were in fact insufficient; therefore, as the intervention deepens, their self-ratings of AS may decrease. At the same time, this may also lead them to experience negative emotions such as confusion and self-blame during the intervention process, thereby affecting intervention outcomes. For example, they may feel confused or blame themselves because parenting behaviors they thought were "positive" are actually "somewhat negative." Thus, interventionists need to be better able to respond to the emotions of this type of parent.

4.2 How the intervention effects of parental autonomy support transfer to children' s executive function

Another key question explored in this study is how the intervention effects of parents' AS transfer to children' s EF. Based on the present findings, we discuss this issue from the following aspects.

First, by comparing children' s EF at pretest and posttest in the intervention and control groups, we found that the main effect of group, the main effect of time, and the interaction between the two were all nonsignificant. This indicates that, at the end of the intervention, the intervention targeting parents' AS had not brought about changes in children' s EF. However, in the follow-up assessments, children' s daily EF abilities in the intervention group gradually improved (BRIEF scores gradually decreased), and at follow-up 2, children' s daily EF was significantly better than at pretest, posttest, and follow-up 1. This

result indicates that the intervention effects of parents' AS require a certain time lag before they transfer to children' s EF. This may be because children' s EF, as a complex and stable higher-order cognitive ability, requires sustained transformation and accumulation in parents' AS before improvements can gradually emerge. This finding further emphasizes the long-term influence of parental AS behaviors in the family environment on the development of children' s EF.

Second, further correlation analyses and comparisons between the positive and negative groups revealed the relationship between the amount of benefit parents gained from the intervention and changes in children's daily EF. The correlation analysis showed that, in the intervention group, greater changes in parents' AS were significantly associated with greater changes in children' s daily EF. Comparisons between the positive and negative groups showed that, before the intervention, when parents obtained positive improvements in AS through the intervention, children' s daily EF also improved during the follow-up phase; in particular, at follow-up 2, daily EF showed a significant improvement compared with pretest, posttest, and follow-up 1. Conversely, when parents' AS instead decreased after the intervention, children' s daily

Although daily EF also showed a downward trend, it did not reach statistical significance. These results indicate that the benefits parents gained from the AS intervention could be transferred to children' s daily EF, and that the greater the parents' gains, the greater the changes in children' s daily EF.

However, in this study, differences in children' s accuracy and reaction time on the DCCS task at pretest, posttest, and follow-up were not significant. Previous studies have shown that parental AS is closely related to children' s optimal and daily EF (Distefano & Meuwissen, 2022). Yet the present study found that the intervention effect of parental AS transferred only to daily EF, not to optimal EF. Optimal EF, also referred to as domain-general EF or trait EF, is related to the efficiency of executive function and reflects the level of executive functioning an individual displays under optimal conditions (or when given the opportunity to be under optimal conditions); it is associated with the maturity of brain development (Holochwost et al., 2023). Although it is influenced by the environment, this influence stems from gradual development after long-term environmental immersion, rather than from rapid development brought about by short-term change (Holochwost et al., 2023). Daily EF, also referred to as domain-specific EF or state EF, reflects the typical level of executive-function skills an individual displays in everyday contexts and goal pursuit; it is a control skill that serves specific goals and is influenced by context (Doebel & Müller, 2023; Ibbotson, 2023). When the family caregiving environment changes, it may be rapidly affected (Ibbotson, 2023; Niebaum et la., 2025). After receiving the AS intervention, on the one hand, parents may have adopted more AS behaviors and promoted positive changes in children' s daily behavior, which in turn led parents to give better evaluations of children' s daily EF; on the other hand, parents' understanding and acceptance of children increased, reducing some of their original negative evaluations of children' s daily behavior and

thereby increasing their positive evaluations of children' s daily EF. Changes in parenting behavior, changes in evaluations of children's behavior, and changes in children' s daily behavior may all bring changes to the child' s family caregiving environmental system; and enduring, positive systemic changes will provide a good foundation for children' s brain development and ultimately promote better performance by children on optimal EF tasks. This possibility deserves continued in-depth exploration in future research.

4.3 Research Significance and Limitations

Compared with previous studies, the theoretical breakthroughs and practical value of this study are reflected in the following aspects. First, most previous studies on parental AS interventions have only answered the question of whether the intervention is effective, but have not revealed what the process of intervention change is like. Through intensive data collection, the present study answered this question. The study found that the effects of parental AS intervention emerged after the second intervention session, gradually improved as the intervention progressed, and remained stable during the follow-up phase. This trajectory of change suggests that the content of the first two intervention sessions may be an important factor influencing intervention effects.

Second, this study found that not all parents who participated in the intervention benefited positively (the positive-change group); for some parents, AS decreased after the intervention (the negative-change group). Further analysis showed that the two groups of parents differed in their pre-intervention AS levels, and that the trajectories of AS change differed between the two groups during the intervention and follow-up periods. This new finding suggests that, when designing intervention programs in future research, it is necessary to fully consider parents' baseline levels and to design parent-intervention courses targeted to parents at different ability levels.

Again, according to ecosystem theory and other theories, changes in parenting behavior affect changes in children' s psychology and behavior, a point that has already been confirmed by many longitudinal follow-up studies. However, at present, few intervention studies have revealed whether and how parents' gains in interventions transfer to changes in children' s EF. The present study fills this gap. This study found for the first time that the transfer effects of parental AS intervention effects differed for children' s daily EF and optimal EF: AS intervention effects transferred to children' s daily EF, but did not transfer to children' s optimal EF; the differences in transfer effects may be related to the different connotations of the two types of EF.

This study also has the following limitations. First, this study intervened with only one parent in the family (the father or the mother). However, children' s development involves interactions within the family as a whole. Future research may consider including both parents jointly in intervention programs, and, by designing intervention protocols suitable for coparental participation, examine

the mechanisms by which parental synergy affects children' s EF. Second, this study found that the parental AS intervention effect did not transfer to children' s optimal EF. One possible reason is that the intervention period and follow-up period were relatively short. Future research may appropriately extend the intervention and follow-up periods in order to evaluate the long-term stability of intervention effects more comprehensively. Again, this study used a questionnaire method rather than an observational method to assess parental AS. Although some literature indicates that the correlation between the two assessment approaches is high, this still cannot avoid the methodological bias introduced by a single assessment method. Future research still needs to use multiple methods to assess parental AS.

5. Conclusion

This study examined the trajectory of change in participating parents' autonomy support before, during, and after the autonomy-support intervention, as well as the influence of this change on children' s executive function. Regarding the effects and change trajectories of the parental AS intervention, the study found that the intervention could effectively change parental AS; the intervention effect was already evident after the second intervention session, and the effect further improved as the intervention progressed, remaining stable during the follow-up phase. However, the intervention effect was influenced by parents' pre-intervention baseline level of AS: the lower the parental AS baseline level, the better the intervention effect. Regression analyses found that not all parents' AS benefited from the intervention; there were differences in the AS change trajectories of the positive-change group (i.e., parents' AS levels significantly increased after the intervention) and the negative-change group (i.e., parents' AS levels decreased after the intervention). Regarding transfer effects, this study found that the parental AS intervention effect could transfer to children' s daily EF rather than optimal EF: the better the parental intervention effect, the greater the change in children' s daily EF, but the transfer had a certain time lag. In sum, this study provides a theoretical extension for clarifying the potential mechanisms by which intervention improves parental AS and the potential mechanisms by which parental AS intervention effects transfer to children' s EF.

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Parental Autonomy Support Intervention:

Baseline' s effect in Effectiveness, Change Trajectory, and Executive Function Transfer to Children

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Abstract

Previous studies show interventions can boost parental autonomy support (AS), but its change trajectory, influencing factors, and far-transfer effects on children' s executive function (EF) are unexplored. This study aims to examine these.

A total of 159 pairs of children in grades 1-3 of primary school and their parents participated in the AS intervention study and were randomly divided into an intervention group (79 pairs) and a control group (80 pairs). Parents in the intervention group received a 4-week offline AS intervention course with one 2-hour session per week. They underwent multiple tests, while children in this group took some EF scale and tasks. In the control group, parents received public account push notifications, and both parents and children only underwent pre- and post-tests, with the test content being the same as that in the intervention group.

Compared to the control group, parents in the intervention group had a significant post-test increase in AS. The effect appeared in the second intervention, improved progressively, and stayed stable during follow-up. A lower pre-test AS baseline predicted a better effect. Retrospective analysis showed differing AS change trajectories between positive (AS increase) and negative (AS decrease) groups. Moreover, the AS intervention effect transferred to children' s daily EF, not optimal EF, during follow-up and was influenced by baseline AS levels.

Taken together, the baseline level of parents' AS at the pre-test influences the intervention effect of AS, the trajectory of intervention change, and the transfer effect on children' s EF.

Keywords Parental autonomy support intervention, Executive function, Change trajectory, Transfer effect

Appendix Table 1. Structured Group for Parents' Autonomy Support Intervention

Theme	Course Content	After-Class Assignment
Session 1	1. Introduce the physical and psychological development and learning characteristics of early school-age children; 2. Using common academic parent-child conflicts as examples, introduce conflict maps.	Using the most recent conflict between oneself and one' s child as an example, draw a parent-child conflict map.
Session 2	1. Using academic parent-child conflicts as examples, analyze the relationships between the reactions of the parent and child and the outcomes of their interaction; clarify parents' intrusive and controlling behaviors in conflicts, define the division of responsibility in parent-child conflicts, and help parents establish an awareness of authority and responsibility.	Based on the conflict map, analyze each party' s reactions and the needs behind them.

Theme	Course Content	After-Class Assignment
Session 3	1. Introduce autonomy-supportive parenting methods and the parental role in the autonomy-support process; 2. Practice parents' skills in noticing conflicts and self-regulating during conflicts.	Try to establish a toolbox for self-awareness and regulation.
Session 4	1. Introduce autonomy-support skills, including cognition, emotion, behavior, and the parent–child relationship; 2. In light of common needs in children' s academic situations, practice autonomy-support skills.	In subsequent academic parent–child interactions, try to practice autonomy support.

Appendix Table 2. Pairwise comparisons among measurement time points for parents' AS and children' s EF

Variable	Measurement time point	Comparison observation point	Mean difference	Standard error	Significance
AS	Pretest	Midtest 1	-0.139	0.074	0.067
AS	Pretest	Midtest 2	-0.273*	0.066	0.000
AS	Pretest	Midtest 3	-0.310*	0.076	0.000
AS	Pretest	Posttest	-0.242*	0.069	0.001
AS	Pretest	Follow-up 1	-0.255*	0.074	0.001
AS	Pretest	Follow-up 2	-0.284*	0.065	0.000
AS	Midtest 1	Pretest	0.139	0.074	0.067

Variable	Measurement time point	Comparison observation point	Mean difference	Standard error	Significance
AS	Midtest 1	Midtest 2	-0.134*	0.054	0.016
AS	Midtest 1	Midtest 3	-0.171*	0.059	0.005
AS	Midtest 1	Posttest	-0.103	0.053	0.056
AS	Midtest 1	Follow-up 1	-0.116	0.065	0.079
AS	Midtest 1	Follow-up 2	-0.145*	0.065	0.029
AS	Midtest 2	Pretest	0.273*	0.066	0.000
AS	Midtest 2	Midtest 1	0.134*	0.054	0.016
AS	Midtest 2	Midtest 3	-0.037	0.059	0.536
AS	Midtest 2	Posttest	0.031	0.049	0.535
AS	Midtest 2	Follow-up 1	0.019	0.061	0.762
AS	Midtest 2	Follow-up 2	-0.011	0.065	0.868
AS	Midtest 3	Pretest	0.310*	0.076	0.000
AS	Midtest 3	Midtest 1	0.171*	0.059	0.005
AS	Midtest 3	Midtest 2	0.037	0.059	0.536
AS	Midtest 3	Posttest	0.068	0.054	0.213
AS	Midtest 3	Follow-up 1	0.056	0.061	0.365
AS	Midtest 3	Follow-up 2	0.026	0.067	0.697
AS	Posttest	Pretest	0.242*	0.069	0.001
AS	Posttest	Midtest 1	0.103	0.053	0.056
AS	Posttest	Midtest 2	-0.031	0.049	0.535
AS	Posttest	Midtest 3	-0.068	0.054	0.213

Variable	Measurement time point	Comparison observation point	Mean difference	Standard error	Significance
AS	Posttest	Follow-up 1	-0.012	0.051	0.812
AS	Posttest	Follow-up 2	-0.042	0.054	0.441
AS	Follow-up 1	Pretest	0.255*	0.074	0.001
AS	Follow-up 1	Midtest 1	0.116	0.065	0.079
AS	Follow-up 1	Midtest 2	-0.019	0.061	0.762
AS	Follow-up 1	Midtest 3	-0.056	0.061	0.365
AS	Follow-up 1	Posttest	0.012	0.051	0.812
AS	Follow-up 1	Follow-up 2	-0.029	0.053	0.580
AS	Follow-up 2	Pretest	0.284*	0.065	0.000
AS	Follow-up 2	Midtest 1	0.145*	0.065	0.029
AS	Follow-up 2	Midtest 2	0.011	0.065	0.868
AS	Follow-up 2	Midtest 3	-0.026	0.067	0.697
AS	Follow-up 2	Posttest	0.042	0.054	0.441
AS	Follow-up 2	Follow-up 1	0.029	0.053	0.580
BRIEF	Pre-test	Post-test	0.005	0.031	0.874
BRIEF	Pre-test	Follow-up test 1	0.013	0.030	0.672
BRIEF	Pre-test	Follow-up test 2	0.080*	0.028	0.006
BRIEF	Post-test	Pre-test	-0.005	0.031	0.874
BRIEF	Post-test	Follow-up test 1	0.008	0.033	0.815
BRIEF	Post-test	Follow-up test 2	0.075*	0.031	0.019

BRIEF	Follow-up test 1	Pre-test	-0.013	0.030	0.672
BRIEF	Follow-up test 1	Post-test	-0.008	0.033	0.815
BRIEF	Follow-up test 1	Follow-up test 2	0.067*	0.026	0.013
BRIEF	Follow-up test 2	Pre-test	-0.080*	0.028	0.006
BRIEF	Follow-up test 2	Post-test	-0.075*	0.031	0.019
BRIEF	Follow-up test 2	Follow-up test 1	-0.067*	0.026	0.013

Note: * indicates P < 0.05.

Appendix Table 3. Pairwise comparisons between measurement time points for parent AS and child EF in the positive-change and negative-change groups

Time point	Comparison time point	Parent AS: Positive-change group Mean difference	Parent AS: Positive-change group Standard error	Parent AS: Positive-change group Significance	Parent AS: Negative-change group Mean difference	Parent AS: Negative-change group Standard error	Parent AS: Negative-change group Significance	Child EF: Positive-change group Mean difference	Child EF: Positive-change group Standard error	Child EF: Positive-change group Significance	Child EF: Negative-change group Mean difference	Child EF: Negative-change group Standard error	Child EF: Negative-change group: Significance
Pretest	Posttest	-.451*	0.065	0.000	0.176	0.110	0.766	0.008	0.042	1.000	-0.001	0.041	1.000
Pretest	Follow-up 1	-.456*	0.078	0.000	0.148	0.109	1.000	0.045	0.035	1.000	-0.052	0.052	1.000
Pretest	Follow-up 2	-.549*	0.047	0.000	.245*	0.078	0.036	0.093	0.037*	0.045	0.054	0.043	1.000
Posttest	Pretest	.451*	0.065	0.000	-0.176	0.110	0.766	-0.008	0.042	1.000	0.001	0.041	1.000
Posttest	Follow-up 1	-0.005	0.066	1.000	-0.028	0.081	1.000	0.037	0.036	1.000	-0.051	0.066	1.000
Posttest	Follow-up 2	-0.097	0.066	0.896	0.069	0.089	1.000	0.085	0.039	0.208	0.055	0.053	1.000

Time point	Comparison time point	Parent AS: Positive-change group Mean difference	Parent AS: Positive-change group Standard error	Parent AS: Positive-change group Significance	Parent AS: Negative-change group Mean difference	Parent AS: Negative-change group Standard error	Parent AS: Negative-change group Significance	Child EF: Positive-change group Mean difference	Child EF: Positive-change group Standard error	Child EF: Positive-change group Significance	Child EF: Negative-change group Mean difference	Child EF: Negative-change group Standard error	Child EF: Negative-change group: Significance
Follow-up 1	Pre-test	.456*	0.078	0.000	-0.148	0.109	1.000	-0.045	0.035	1.000	0.052	0.052	1.000
Follow-up 1	Post-test	0.005	0.066	1.000	0.028	0.081	1.000	-0.037	0.036	1.000	0.051	0.066	1.000
Follow-up 1	Follow-up 2	-0.093	0.063	0.907	0.097	0.091	1.000	0.048	0.035	1.000	0.106	0.036	0.050
Follow-up 2	Pre-test	.549*	0.047	0.000	-.245*	0.078	0.036	-0.093	0.037*	0.045	-0.054	0.043	1.000
Follow-up 2	Post-test	0.097	0.066	0.896	-0.069	0.089	1.000	-0.085	0.039	0.208	-0.055	0.053	1.000
Follow-up 2	Follow-up 1	0.093	0.063	0.907	-0.097	0.091	1.000	-0.048	0.035	1.000	-0.106	0.036	0.050

Appendix: Questionnaires Used in the Study

“Parental Academic Autonomy Support Scale” —Sample Items

Introduction:

Dear parent, hello. Welcome to this survey. We are a research project team from a university, conducting a study on the relationship between parental attitudes and behaviors and children’ s learning behaviors. The survey data will be used only for research purposes, and the security of your personal information will be ensured.

Please carefully read the following statements. They describe some situations in your life. Please choose the appropriate option according to your actual circumstances. The following items describe some of your behaviors and attitudes toward your child. Choose the option that applies to you.

“Does not fit” means: these descriptions do not fit me at all;

"Partly fits" means: these descriptions fit me only in part;

"Generally fits" means: these descriptions fit me somewhat, to a greater extent than "partly fits" ;

"Mostly fits" means: these descriptions fit me in many respects, to a greater extent than "generally fits" ;

"Completely fits" means: these descriptions fit me completely.

Item	Does not fit	Partly fits	Generally fits	Mostly fits	Completely fits
1. When my child has resistant or irritated emotions during learning (such as losing temper, being impatient, withdrawing, feeling frustrated, fearing failure, being uncooperative, etc.), I can usually understand and accept these emotions in my child.					

Item	Does not fit	Partly fits	Generally fits	Mostly fits	Completely fits
2. When my child has resistant or irritated emotions during learning (such as losing temper, being impatient, withdrawing, feeling frustrated, fearing failure, being uncooperative, etc.), I can usually stay calm rather than become irritated.					

Item	Does not fit	Partly fits	Generally fits	Mostly fits	Completely fits
3. When my child has resistant or irritated emotions during learning (such as losing temper, being impatient, withdrawing, feeling frustrated, fearing failure, being uncooperative, etc.), I usually guide him/her gently and patiently to calm down.					

Item	Does not fit	Partly fits	Generally fits	Mostly fits	Completely fits
4. I encourage and respect my child' s learning in his/her own way and at his/her own pace, even when it is sometimes inconsis-tent with my ideas.					

"Children' s Executive Function Scale" —Sample Items

Introduction:

Dear parent, hello. Welcome to this survey. We are a research project team from a university, conducting a study on the relationship between parental attitudes and behaviors and children' s learning behaviors. The survey data will be used only for research purposes, and the security of your personal information will be ensured.

Please carefully read the following statements. They describe some situations of your child in daily life. Please choose the appropriate option according to your actual circumstances. The following items describe some behaviors and attitudes. Choose the option that applies to your child.

"No" means: over the past six months, my child has not shown these behaviors;

"Sometimes" means: over the past six months, my child has sometimes shown these behaviors;

"Often" means: over the past six months, my child has often shown these behaviors.

Item	No	Sometimes	Often
1. When asked to do three things, remembers only the first or the last one.			
2. Has difficulty adapting to new environments (class, group, friends).			
3. Is unable to recognize that his/her own behavior elicits negative reactions from others.			
4. If there is no adult supervision, he/she may become absent-minded or troublesome.			

Note: Figure translations are in progress. See original paper for figures.