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Impact of imitation abilities on social communication in autistic children: evidence from an Early Start Denver Model intervention study

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Abstract
Imitation is foundational to early social learning, yet autistic children often exhibit significant impairments in imitation, potentially impacting their social communication skills. This study examined the relationship between imitation abilities and social communication in autistic children and evaluated the effectiveness of the Early Start Denver Model (ESDM) intervention. The study included 52 autistic children aged 2–5, divided into an experimental group receiving ESDM intervention and a control group undergoing standard rehabilitation. We assessed the children's imitation and social communication skills before and after the intervention. Results indicated a significant positive correlation between imitation and social communication skills both before and after the intervention. Specifically, various forms of imitation (e.g., vocal, gestural, object-related) were closely linked to different domains of social communication (e.g., expressive communication, joint attention, social skills). Baseline imitation levels and improvements in imitation were significant predictors of enhanced social communication, jointly accounting for over half of the observed improvements in social communication, with imitation improvement being the strongest predictor. Age positively moderated the relationship between imitation and social communication, with older children showing a stronger impact of imitation on social communication. Although these effects were evident across groups, the ESDM group showed greater gains in imitation skills compared to the control group. However, we did not find evidence of an intervention effect on social communication skills. This study underscores the critical role of imitation in the social communication development of autistic children. These findings support the enhancement of imitation skills in early interventions for autistic children, highlighting the effectiveness of ESDM in fostering imitation abilities.

Keywords Autism, Imitation, Social communication, Early Start Denver Model (ESDM)

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Introduction

Challenges in social communication are one of the core features of autism, with children on the spectrum often struggling with joint attention, non-verbal communication, and reciprocal social interaction [2]. These challenges significantly impact the adaptive abilities and social participation of autistic children in daily life [23]. Thus, uncovering the underlying mechanisms of social communication impairments in autistic children and improving their social communicative skills remain critical areas of research.

Imitation serves as a foundational element in the early social, linguistic, and emotional development of children [22, 25, 28]. Typically developing children acquire many skills through imitation, such as language, social behaviors, and motor abilities [11, 26]. Concurrently, imitation plays a significant role in the development of social cognition, empathy, and emotional regulation [5, 22]. Moreover, the neural mechanisms involved in imitation overlap but are not identical to those involved in social communication. Areas such as the premotor cortex and the inferior frontal gyrus, closely associated with imitation and populated densely by mirror neurons [4], are also integral to social communication. The inferior frontal gyrus, for instance, is directly responsible for language expression [31], but the neural mechanisms involved in social communication are more extensive. During social tasks, there is synchrony between the activity in the premotor cortex and social cognitive brain areas, including the superior temporal gyrus (language comprehension) and the temporo-parietal junction (joint attention) [38], providing a neural basis for the correlation between imitation and social communication.

However, autistic children often face significant challenges in imitation [1, 3], including difficulties in mimicking simple and complex gestures, issues with recognizing and reproducing facial expressions, and challenges in vocal and language imitation [46]. Early in life, autistic children display marked delays in the development of imitation skills [53]. Compared to typically developing children, those with autism perform worse across a range of imitation tasks including gesture, object manipulation, and oral-facial movements [1, 32, 33, 42, 50]. Although the imitative abilities of autistic children develop over time, the pace of development, the level of skills achieved at different time points, and the ultimate outcomes often differ from those of neurotypical children [15, 29].

Difficulties with imitation may impact the development of social communication skills in autistic children [50]. Research has demonstrated a significant relationship between the imitative abilities of autistic children and their social communication skills. For instance, Dadgar et al. [8] found a significant positive correlation between action imitation and joint attention, with stronger imitation skills correlating with better joint attention abilities in children. The imitative capabilities of autistic children can also predict their future language development; a longitudinal study by Pittet et al. [29] indicated that object and gesture imitation skills in children aged 2 to 5 could effectively predict their expressive language levels one year later. Similarly, Sandbank et al. [40] demonstrated that motor imitation is a strong predictor of later intentional communication in preverbal autistic children. Moreover, imitative abilities are importantly linked to the social skills and emotional recognition abilities of autistic children as shown by Drimalla et al. [10], where the accuracy of facial expression imitation correlated positively with emotional recognition abilities. Supportive interventions can significantly enhance the imitative abilities of autistic children, while also facilitating the development of associated social communication skills such as joint attention, language, and emotional expression [17, 20, 46]. Despite these findings, existing research has its limitations. Firstly, many studies have only explored the relationship between a single type of imitation and one social communication skill, lacking a comprehensive and systematic investigation of various imitation types and multidimensional social communication skills. This individuality restricts a full understanding of the overall relationship between imitation and social communication. Secondly, although existing studies have highlighted the correlation between imitation and social communication abilities in autistic children, they have not fully explored the specific role and impact of imitation in the development of social communication in these children, particularly lacking intervention research evidence that reveals the pathways through which imitation influences social communication skills, which is crucial for devising effective intervention strategies.

The Early Start Denver Model (ESDM) is a comprehensive, naturalistic developmental behavioral intervention that supports social communication in autistic children by using child-directed strategies within a natural, play-based setting to promote overall development [9, 34]. Numerous studies have validated the efficacy of ESDM in improving social communication among autistic children [6, 9, 13, 55]. The ESDM emphasizes fostering social interaction, language, and cognitive development through imitation, with the enhancement of imitative abilities considered one of its strengths [9]. A case study by Waddington [49] found significant enhancements in object manipulation, gesture imitation, and vocal imitation following ESDM intervention. Additionally, individual variations in skills such as imitation and play may influence the outcomes of ESDM interventions [46, 47]. Thus, ESDM potentially serves as an ideal experimental method for studying the dynamic relationship between imitation and social communication in autistic children.

This study aimed to investigate the relationship between imitation abilities and social communication skills in autistic children through a controlled ESDM intervention experiment. We examined the impact of imitation factors on the development of social communication in autistic children and investigated the relationship between different types of imitation (such as vocal, gesture, and object manipulation) and various domains of social communication (such as joint attention and expressive language). This exploration not only expands current research on imitation and social communication in autistic children but also provides theoretical and empirical support for designing more effective early intervention strategies. The study posed three main research questions: (1) Is there a correlation between imitation abilities and social communication in autistic children, and how do different types of imitation relate to various domains of social communication? (2) How do imitation factors influence the extent of improvement in social communication in autistic children, and what factors may affect the benefits derived from improvements in imitation? (3) Does ESDM significantly enhance imitation and social communication skills in autistic children, and does it offer advantages over conventional interventions? The hypotheses of this study included: (1) There is a close correlation between imitation and social communication, with specific relationships existing between different types of imitation and various domains of social communication; (2) Both baseline imitation levels and enhancements in imitation during interventions can impact the improvement of social communication in autistic children, with age potentially acting as a moderating variable; (3) ESDM holds comparative advantages in enhancing imitation and social communication in autistic children. Using a nonrandomized controlled design, this study aimed to deepen the understanding of the relationship between imitation and social communication in autistic children and provide more nuanced insights for interventions that support social communication development in this population.

Table 1 ANCOVA results at baseline between the two groups (Controlling for Age)

	Group (Mean ± SD)		F (ANCOVA)	*P*
	Control Group ($n=24$)	Experimental Group ($n=28$)		
Imitation	10.75 ± 8.84	5.46 ± 5.49	3.4	0.07
Social Communication	123.67 ± 103.67	72.11 ± 46.69	3.2	0.08
Age (months)	45.83 ± 8.97	36.36 ± 9.00		

Note: F and p values are from ANCOVA controlling for age

Methods

Participants

This study recruited 52 autistic children, aged 2 to 5 years. All participants were diagnosed by professional child psychiatrists using standardized diagnostic tools, including the Autism Diagnostic Interview—Revised (ADI-R; [37] and/or the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; [24]. The children were recruited from two autism-specialized educational institutions in mainland China: one offering the ESDM and the other offering conventional rehabilitation interventions. Families did not choose the intervention type; rather, assignment was determined by the institution. Informed consent was obtained from all parents or caregivers, and participant data were anonymized after the extraction of identifying information to ensure privacy.

Participants were assigned to either an experimental group or a control group based on the intervention methods employed at their respective centers, as random assignment was not feasible in our clinical settings. The experimental group included 28 children (21 boys and 7 girls), with a mean age of 36.36 ± 9.00 months, while the control group comprised 24 children (18 boys and 6 girls), with a mean age of 45.83 ± 8.97 months. A significant age difference was observed between the groups, which is attributable to the fact that children in the experimental group were recruited from institutions implementing the ESDM, while the control group children were from institutions using standard interventions. The ESDM prioritizes early intervention, likely resulting in a younger age among children in institutions adopting this approach. We acknowledge that this age difference may have influenced group characteristics, which is a limitation inherent in nonrandomized designs. To address this issue, we have conducted ANCOVA to control age differences between groups. The results showed no significant baseline differences in imitation abilities ($F=3.2$, $p=0.08$) and social communication levels ($F=3.4$, $p=0.07$) (see Table 1).

Assessment tools

For this study, the following evaluation instruments were employed:

Imitation Ability Measure: To comprehensively assess children's imitation abilities, our measure was developed based on several established assessment tools. Specifically, we drew from the Motor Imitation Scale (MIS; [43], particularly its classification of motor imitation. Additionally, we incorporated elements from the Preschool Imitation and Praxis Scale (PIPS; [45], focusing on its assessment of sequential motor actions and oral-facial imitation. Based on the framework of the imitation battery proposed by Rogers et al. [32], we expanded the scope of the measure to include the assessment of vocal

imitation. This multidimensional approach integrates different types of imitation, reflecting the diversity of imitation behaviors and allowing for a more comprehensive capture of children's imitation abilities across various domains. Our measure evaluated imitation abilities across four sub-scales—oral-facial movement imitation, vocal imitation, gesture imitation, and object imitation—comprising a total of 13 assessment items. An unstructured imitation assessment method was used, in which the evaluator did not provide explicit imitation instructions or feedback on the child's responses. This method aimed to capture the child's imitation abilities in a spontaneous social interaction setting. Before the assessment began, the evaluator told the child, "I have many toys, let's play together." The evaluator then used the same toys to mimic the child's play behaviors. After an initial phase of incidental imitation, the evaluator began to demonstrate actions with the toys, saying before each demonstration, "Watch me, I am going to start playing," followed by demonstrating an action and describing it verbally. The child was then given 5 s to respond, with each action demonstrated up to three times. Scoring was based on the child's performance, ranging from 0 to 2 points (0 = no imitation if the child failed to imitate the action after three demonstrations; 1 = partial imitation if the child attempted to imitate the evaluator's action but lacked accuracy; 2 = complete imitation if the child could accurately and promptly imitate the action after any demonstration). For instance, if the evaluator demonstrated clapping and the child accurately and promptly imitated the clapping after any demonstration, a score of 2 was awarded; a score of 1 was given if the child imitated the action but with less accuracy or timeliness; and a score of 0 was assigned if the child failed to imitate the clapping after three demonstrations.

Social Communication Ability Measure: This study utilized the social communication section of the ESDM curriculum checklist (ESDM-CC) [35] to assess the social communication skills of autistic children. The ESDM-CC is a systematic and highly detailed curriculum-based measure that references the developmental sequence of related skills across various domains for children. It was designed to derive individualized goals by assessing each child's current ability level [36]. Because it captured the short-term changes in skills that were directly targeted by the intervention, it was therefore referred to as a proximal measure [39] of intervention effects. Moreover, its sensitivity in detecting subtle changes aligned with the design of this study, which is why it was selected as the assessment measurement for social communication. The social communication measure used in this study comprised four sub-scales: receptive communication, expressive communication, joint attention, and social skills, totaling 219 items. A three-level scoring system (0 to 2 points) was employed, where 0 points indicated failure, meaning the behavior was not observed or was difficult to elicit; 1 point indicated pass/failure, where the skill did not consistently appear; and 2 points indicated pass, where the skill was consistently demonstrated or had been mastered [35]. Higher scores represented better social communication abilities.

Procedure

Both the experimental and control group children underwent a 12-week intervention period. The experimental group received ESDM intervention, consisting of 100 min per day, five days a week, totaling 100 h. The control group engaged in conventional rehabilitation training 4 to 5 days per week, each session lasting 80 to 120 min, with an average total intervention time of 100.67 h. There was no significant difference in the total duration of intervention between the two groups.

Assessments in this study were conducted at two time points: (1) pre-intervention, to collect baseline data on children's imitation abilities and social communication skills; and (2) post-intervention, to reassess the same abilities and skills after 12 weeks using the same tools and methodologies. All assessments were conducted by three assessors. To prevent any potential bias, the assessors were not informed about the specific intervention methods or the study hypotheses. The assessors only evaluated the children's performance based on the standardized procedures provided, without access to any information regarding the nature of the intervention or the study's aims. Moreover, all assessors underwent standardized training to ensure consistent evaluation methods across all participants. The evaluation process was carefully structured to minimize variability and ensure that both the imitation and social communication assessments were conducted uniformly.

Intervention procedure

Experimental Group: Participants in the experimental group received tailored interventions based on the ESDM. Three experienced therapists, each with over four years of experience and certified in ESDM techniques with over 80% proficiency, conducted the interventions. The sessions took place in therapy rooms equipped with cameras and age-appropriate educational materials such as blocks, puzzles, and toys. The ESDM intervention was interest-driven and structured around interactive play, divided into two main phases: becoming an active participant in play, where therapists used strategies to engage children and position themselves as helpers and reinforcers; and developing joint routine activities, which consisted of four stages—setting the environment, thematic play involving object games like block building or social games like singing and dancing, expanding and

generalizing the play to maintain interest and broaden skills, and a closing routine involving rituals like cleaning up to end the session. Each game initially lasted 2–5 min, extending up to 10 min over time, and within the 100-minute session, all activities were designed to review mastered skills and practice new target skills.

Control Group: Participants in the control group underwent conventional rehabilitation training, which involved a variety of standard and widely recognized psychological interventions tailored to each child's specific needs. These interventions included cognitive training, speech therapy, sensory integration training, and social play activities, without a fixed protocol to allow flexibility. All interventions were conducted at institutions specializing in autism education and rehabilitation.

Community involvement statement

Community members were not involved in the development of the research questions, selection of data collection tools, or interpretation of findings.

Results

Relationship between imitation ability and social communication in autistic children

Correlation between imitation and social communication levels

We combined the imitation and social communication data from both participant groups and conducted correlation analyses to explore their association in autistic children. Pearson correlation analysis revealed significant positive correlations between imitation and social communication scores at both pre- and post-intervention time points (Pre-intervention: $r = 0.91$, $p < 0.01$; Post-intervention: $r = 0.75$, $p < 0.05$). Further analysis revealed a significant positive correlation between the change scores in imitation ability and those in social communication ($r = 0.65$, $p < 0.01$), calculated as the differences between pre- and post-intervention scores. Indicating a close relationship between these skills in autistic children.

We also performed partial correlation analyses on the four subcomponents of imitation and social communication, controlling for aggregate scores of imitation and social communication scores, as well as age, to examine the independent relationships between their subcomponents.

Table 2 Partial correlation analysis of imitation and social communication subdomains (Controlling for Age)

	Object Imitation	Gesture Imitation	Oral-facial Imitation	Vocal Imitation
Receptive Communication	0.009	-0.053	0.13	-0.007
Expressive Communication	0.068	-0.371**	-0.082	0.313**
Social Skills	-0.117	0.362**	-0.025	-0.231*
Joint Attention	0.183	0.037	-0.028	-0.118

Note: *$p < 0.05$, **$p < 0.01$

Partial correlation analyses from Table 2 revealed several significant findings: There were strong positive partial correlations between vocal imitation and expressive communication, and between gesture imitation and social skills, indicating a close relationship between vocal imitation with expressive communication, and gesture imitation with social skills in autistic children. Additionally, the relationship between object imitation and joint attention approaches significance. Notably, some negative correlations, such as between gesture imitation and expressive communication, and between vocal imitation and social skills, were also observed. These negative correlations, resulting from controlling overall scores, without this control, all subcomponents of imitation and social communication would show significant positive correlations. Thus, these negative values indicated a relative reduction in association strength rather than a true negative relationship.

Impact of imitation factors on social communication improvement

To investigate the impact of imitation on social communication improvement—a primary goal in autism interventions—we conducted a regression analysis. First, we combined data from both the experimental group and the control group into a unified dataset. The improvement in social communication, defined as the difference between post-test and pre-test scores, was used as the dependent variable. Independent variables included all potential factors that might influence the improvement in social communication: age at pre-test, imitation at pre-test, change in imitation, and social communication at pre-test.

The stepwise regression model identified baseline imitation and change in imitation as significant predictors of social communication improvement ($p < 0.01$). The standardized coefficients were 0.81 for changes in imitation and 0.31 for baseline imitation, with an adjusted R^2 of 0.48 and $VIF = 1.32$, indicating no multicollinearity.

Further subgroup regression analyses within the ESDM and conventional intervention groups, using the significant predictors identified in the earlier stepwise regression (baseline imitation and change in imitation), confirmed these findings (see Table 3). In the ESDM group, both change in imitation and baseline imitation were significant predictors (standardized coefficients of 0.88 and 0.26, respectively, with an adjusted R^2 of 0.67). In the conventional intervention group, change in imitation was a significant predictor, while baseline imitation was marginally significant (standardized coefficients of 0.84 and 0.36, respectively, with an adjusted R^2 of 0.46).

Table 3 Regression analysis of the impact of imitation factors (including improvement degree and baseline level) on the enhancement of social communication skills

Group		Standardized Coefficients	t	*p*	VIF	R^2	Adjusted R^2	F
Combined Sample ($n=52$)	Imitation (Difference)	0.81	6.95	< 0.01**	1.32	0.50	0.48	$F(2,49)=24.48, p<0.01$
	Imitation (Pre-test)	0.31	2.69	0.01**	1.32			
ESDM Group ($n=28$)	Imitation (Difference)	0.88	7.50	< 0.01**	1.11	0.69	0.67	$F(2,25)=28.16, p<0.01$
	Imitation (Pre-test)	0.26	2.22	0.04*	1.11			
Conventional Group ($n=24$)	Imitation (Difference)	0.84	4.57	< 0.01**	1.41	0.50	0.46	$F(2,21)=10.62, p<0.01$
	Imitation (Pre-test)	0.36	1.97	0.06	1.41			

Dependent Variable: Social Communication (Difference)

*Note: *p < 0.05, **p < 0.01*

Table 4 The moderating effect of age on the relationship between imitation and social communication for the combined dataset ($n=46$)

	Model 1			Model 2			Model 3		
	t	*p*	β	t	*p*	β	t	*p*	β
Imitation (Pre-test)	2.54	0.02*	0.28	2.38	0.02*	0.27	2.53	0.02*	0.25
Imitation (Difference)	6.31	< 0.001**	0.70	5.99	< 0.001**	0.72	6.76	< 0.001**	0.71
Age (Months)				0.55	0.58	0.07	1.08	0.29	0.12
Imitation (Difference) * Age (Months)							3.76	0.001**	0.36
R^2	0.49			0.50			0.63		
Adjusted R^2	0.47			0.46			0.59		
F-value	$F(2,43)=20.933, p<0.001$			$F(3,42)=13.833, p<0.001$			$F(4,41)=17.146, p<0.001$		
ΔR^2	0.49			0.00			0.13		
ΔF-value	$F(2,43)=20.933, p<0.001$			$F(1,42)=0.307, p<0.001$			$F(1,41)=14.121, p=0.001$		

Dependent Variable: Social Communication (Difference)

Note: * $p<0.05$, ** $p<0.01$

In summary, the regression analyses indicated that imitation abilities, both baseline levels and improvements, played a significant and positive role in enhancing social communication skills in autistic children. Improvements in imitation abilities had a stronger predictive effect, while baseline imitation levels also contributed to future social communication improvements, albeit to a lesser extent.

The predictive role of imitation on social communication is moderated by age — a moderation effect model

The regression analyses indicated that imitation factors (baseline levels and improvement) have a strong positive predictive effect on the improvement of social communication skills in autistic children across the ESDM group, the conventional intervention group, and the combined dataset. However, the coefficients of the independent variables and the R^2 values varied among these groups. Given the significant age differences between the two groups, age may moderate the impact of imitation abilities on social communication skills.

To test the moderating effect of age, we conducted moderation analyses based on the regression analysis results. Specifically, change in imitation was used as the independent variable, age as the moderator, change in social communication as the dependent variable, and baseline imitation as a control variable. Moderation analyses were performed separately for the combined dataset, the experimental group, and the control group. Additionally, to address potential ceiling effects (where baseline imitation scores are at or near maximum, leading to changes in imitation approaching or equal to zero, which could severely affect the moderating effect), we applied a ceiling treatment to baseline imitation data (pre-test), removing the top 10% of scores.

The moderation analysis for the combined dataset revealed that baseline imitation, change in imitation, and the interaction between change in imitation and age were all significant, while the impact of age alone was not significant ($p>0.05$) (see Table 4). This suggested a significant moderating effect of age. Adding the interaction term between change in imitation and age (in months) significantly improved the fit of the regression model, with the adjusted R^2 increasing from 0.46 to 0.59 (ΔR^2 = 0.13), indicating that the interaction term contributed an additional 13% to the explanation of the dependent variable. The ΔF value was 14.12, reaching significance ($p<0.001$), indicating a significant improvement in the regression model due to the interaction term.

A simple slopes analysis (Fig. 1; Table 5) revealed that the effect of imitation changes on social communication varies by age. The greatest impact was observed at an older age (mean age + 1 *SD*, ~ 50 months; regression coefficient = 7.33), with decreasing effects at mean age

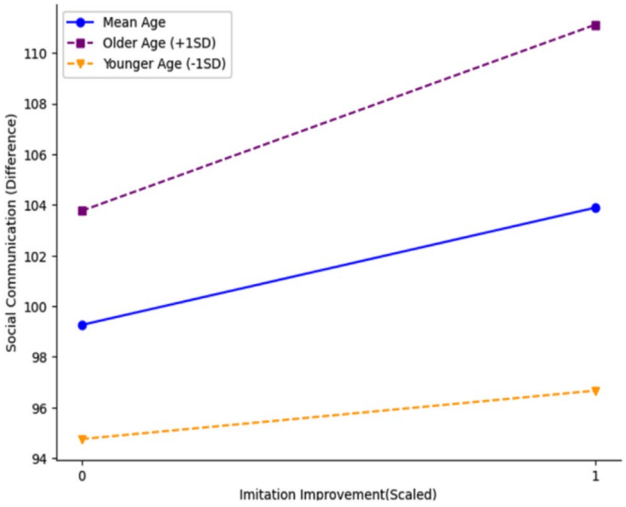

Fig. 1 Simple Slope Analysis of the Impact of Imitation Improvement on Social Communication at Different Levels of Age

Table 5 Simple slope analysis results for the relationship between imitation change and social communication change at different levels of age

Age Level	Regression Coefficient	t	*p*	95% CI	
Mean Age	4.74	7.06	< 0.001	3.42	6.05
High Level (+ 1SD)	7.33	7.54	< 0.001	5.42	9.23
Low Level (-1SD)	2.15	2.19	0.03	0.22	4.07

(40 months; coefficient = 4.74) and a younger age (mean age − 1 *SD*, ~ 30 months; coefficient = 2.15). This indicates that age positively moderates the relationship between imitation improvements and social communication gains in autistic children.

To verify the stability of the moderating effect across different groups, we included group membership as a random effect variable in the model and conducted a mixed-effects analysis (Table 6). The independent variables included pre-test imitation scores and imitation change scores, with age (in months) as the moderating variable and group membership as a control variable.

The results of the mixed-effects model indicated that the moderating effect of age was significant and remained consistent across both the experimental and control groups. Specifically, the interaction term for "imitation change * age" was significant ($\beta = 0.245$, $p < 0.001$), suggesting that the positive impact of imitation change on social communication increased with age. The main effects of pre-test imitation scores ($\beta = 1.879$, $p = 0.004$) and imitation change scores ($\beta = 4.895$, $p < 0.001$) on changes in social communication were also significant. However, age as a main effect did not directly influence the change in social communication scores ($p = 0.624$). The simple slopes analysis is shown in Fig. 2.

In summary, the moderation effect model revealed that age significantly moderated the predictive relationship between imitation abilities and social communication skills in autistic children. As age increased, the impact of imitation improvements on enhancing social communication became more pronounced and was consistent across both the ESDM and conventional intervention groups.

Significant improvement in imitation abilities through the Early Start Denver Model intervention

Overall intervention effects on imitation and social communication abilities

Due to age differences between the two groups, we conducted an ANCOVA with age as a covariate to enhance the evaluation of the intervention effect.

Both the ESDM and control groups showed significant improvements in imitation abilities and social communication scores from pre- to post-intervention (see Table 7). These results suggest that both interventions likely supported development in autistic children, although maturation effects cannot be ruled out.

We conducted a two-way mixed ANOVA (Groups: ESDM vs. conventional intervention; Time: pre-test vs. post-test), with age as a covariate, to examine the effects on improving imitation abilities and social communication skills.

For imitation abilities, there was a significant main effect of time ($F(1,50) = 22.09$, $p < 0.001$) and a significant time by group interaction ($F(1,50) = 4.54$, $p < 0.05$), indicating differences in imitation ability changes between the groups. Simple effects tests revealed that while the control group had a higher mean imitation ability at baseline (7.16 vs. 5.46), the ESDM group surpassed the control group post-intervention (19.54 vs. 16.05), showing a significantly greater improvement (see Fig. 3A).

For social communication skills, there was a significant main effect of time ($F(1,50) = 23.964$, $p < 0.001$), indicating

Table 6 Mixed effects model results for moderating effect of age across groups

Variable	β	Std. Err.	z	*p*	95% CI	
Imitation (Pre-test)	1.879	0.658	2.857	0.004 **	0.590	3.168
Imitation (Difference)	4.895	0.662	7.396	< 0.001 ***	3.598	6.192
Age (Months)	0.208	0.424	0.490	0.624	-0.624	1.039
Imitation (Difference) * Age (Months)	0.245	0.067	3.627	< 0.001 ***	0.112	0.377
Group Variance	54.280	4.062	—	—	—	—

Note: $^{**}p < 0.01$, $^{***}p < 0.001$

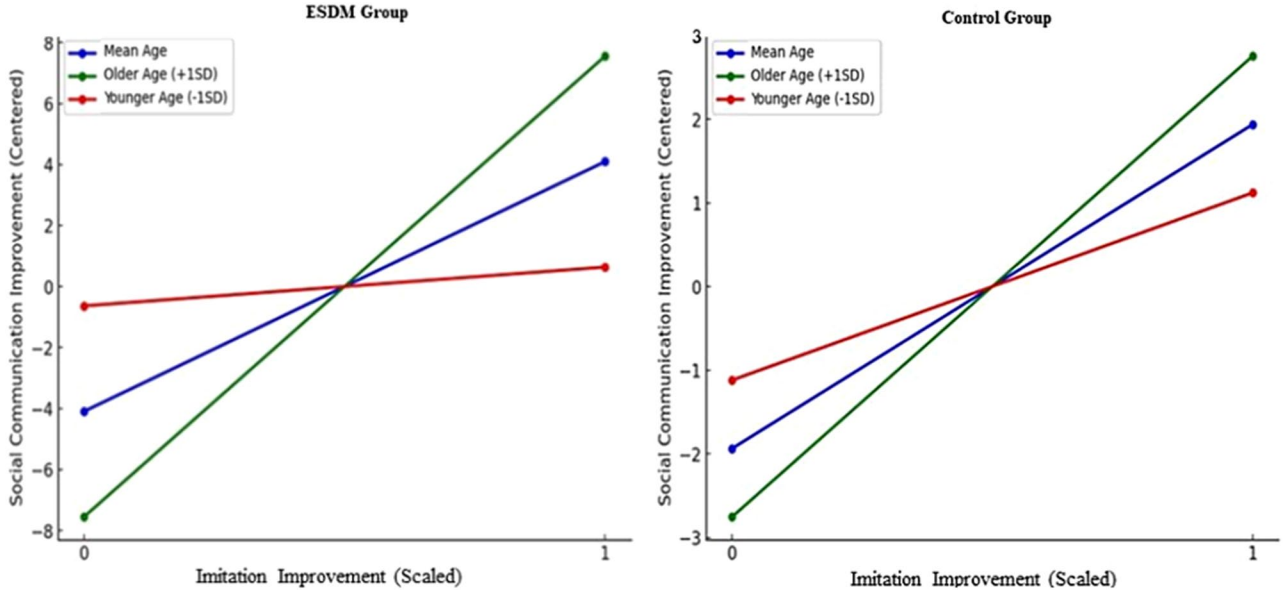

Fig. 2 Simple slope analysis of the impact of imitation change on social communication change at different levels of age in two groups

Table 7 Descriptive statistics of imitation ability and social communication scores in Pre- and Post-test for the control and ESDM group

		Pre-test	Post-test	t	*p*
Control Group ($n=24$)	Imitation	10.75 ± 8.84	18.04 ± 7.46	7.812	< 0.001***
	Social Communication	123.67 ± 103.67	220.25 ± 106.07	11.471	< 0.001***
ESDM Group ($n=28$)	Imitation	5.46 ± 5.49	19.54 ± 7.12	11.4	< 0.001***
	Social Communication	72.11 ± 46.69	175.21 ± 59.60**	14.916	< 0.001***

Note: $^{**}p<0.01$, $^{***}p<0.001$

improvements in both groups. However, the time by group interaction was not significant ($F(1,50)=0.003$, $p>0.05$), demonstrating that the ESDM intervention did not facilitate significantly greater gains in social communication skills compared to the control group (see Fig. 3B).

Intervention effects on subcomponents of imitation and social communication

Further analysis of the pre- and post-intervention data for each subcomponent revealed significant improvements in all imitation and social communication subcomponents for both the ESDM and control groups ($p<0.01$).

Using the difference between post-test and pre-test scores as indicators of improvement, ANCOVA was conducted with age as a covariate. The ANCOVA results for

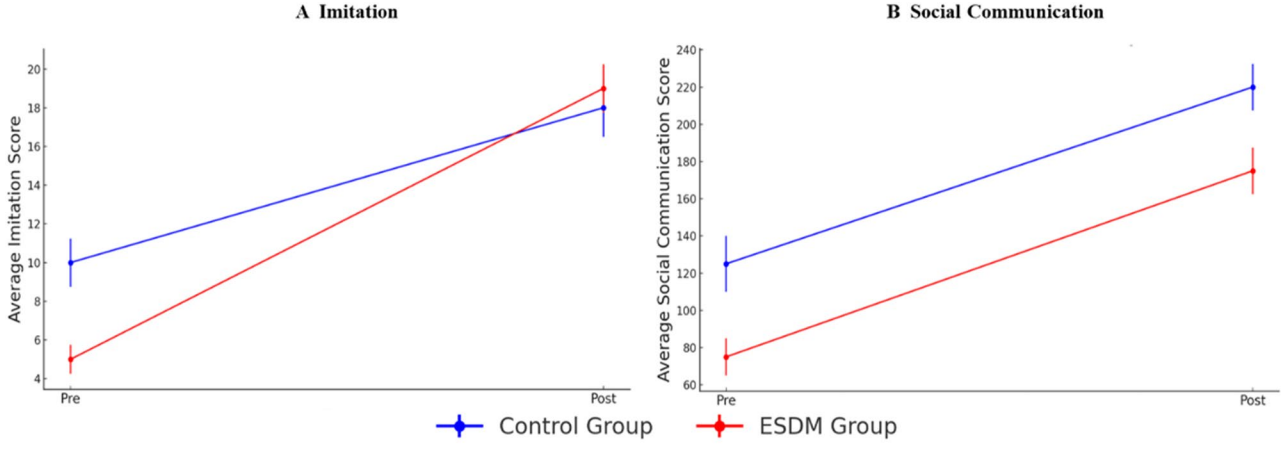

Fig. 3 Pre- and post-test comparison of imitation (**A**) and social communication (**B**) scores between two groups

Table 8 Results of covariance analysis on the improvement of imitation and social communication subcomponents for the control and ESDM group (Controlling for Age)

	Subcomponent	Mean ± SD		*F*	*P*
		Control Group ($n=24$)	ESDM Group ($n=28$)		
Imitation	Object Imitation	1.29 ± 1.12	2.29 ± 1.49	4.728	0.035*
	Gesture Imitation	3.04 ± 1.97	6.29 ± 3.09	7.343	0.009**
	Oral-facial Imitation	0.50 ± 0.59	1.25 ± 0.89	6.039	0.018*
	Vocal Imitation	2.46 ± 2.08	4.25 ± 2.63	2.958	0.092
Social Communication	Receptive Communication	28.96 ± 15.18	33.11 ± 13.90	0.357	0.553
	Expressive Communication	33.04 ± 15.46	34.68 ± 17.98	0.066	0.799
	Social Skills	28.33 ± 14.65	29.50 ± 12.67	0	0.991
	Joint Attention	6.25 ± 4.47	5.82 ± 3.69	0.522	0.473

Note: *$p<0.05$, **$p<0.01$

imitation subcomponents improvement are presented in Table 8.

In the subcomponents of imitation abilities, significant differences were observed between the ESDM and control groups in the improvement of object imitation, gesture imitation, and oral-facial imitation ($p<0.05$). This indicated that the ESDM group exhibited more significant improvements in all types of imitation abilities except for vocal imitation. The improvement in vocal imitation, while higher in the ESDM group, did not reach a significant level ($p=0.09$). Figure 4 illustrates the differences in the improvement of imitation subcomponents between the two groups.

In the social communication subcomponents, the differences in improvement scores between the four subcomponents were minimal, with no significant differences between the experimental and control groups (see Table 8; Fig. 4).

Overall, these results suggest that ESDM intervention has led to significantly greater improvements in imitation abilities compared to conventional intervention, with notable differences observed in all imitation subcomponents except for vocal imitation. However, this study's non-randomized design requires cautious interpretation of its results, as it may have introduced selection bias that complicates attributing improvements in imitation abilities solely to the ESDM intervention. The potential bias may also impact the generalizability of the findings. Although the average improvement in social communication was higher in the ESDM group, this difference did not reach statistical significance.

Discussion

This study empirically demonstrated a close relationship between imitation abilities and social communication skills in autistic children. Further analysis of the subcomponents revealed strong correlations between different types of imitation (object imitation, vocal imitation, gesture imitation, and oral-facial imitation) and social communication subcomponents (joint attention, receptive/expressive communication, and social skills). Imitation

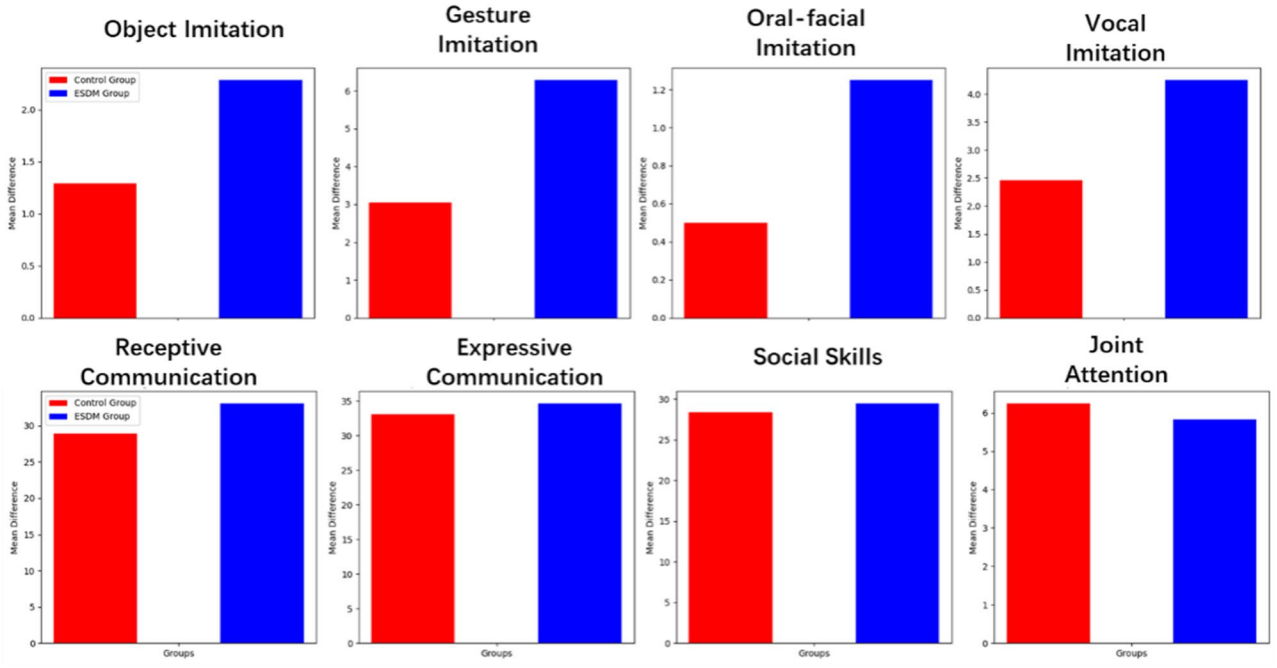

Fig. 4 Comparison of improvement in imitation and social communication subscores for the control and ESDM group

factors, including baseline levels and improvements, significantly predicted social communication enhancements in autistic children. Additionally, the relationship between imitation and social communication was moderated by the age of the children. Our findings also confirm that ESDM intervention significantly enhances imitation abilities in autistic children.

Relationship between imitation abilities and social communication skills in autistic children

At both pre- and post-intervention time points, imitation abilities were positively correlated with social communication skills in autistic children. Notably, vocal imitation showed a stronger association with expressive communication, suggesting it might be a crucial factor in enhancing expressive communication abilities in autistic children. Imitation is considered a key mechanism for language acquisition in typically developing infants [14, 21]. Previous studies have found that vocal imitation [41] and motor imitation, including body movements and object actions [29], are predictors of expressive language development. Our study further clarified the unique role of vocal imitation in this process. Through vocal imitation, autistic children might have found it easier to learn and replicate language and speech patterns, thereby improving their expressive abilities in real social situations. Supporting vocal imitation might be an essential strategy for interventions aimed at improving the language skills of autistic children. The positive correlation between gesture imitation and social skills highlighted the importance of non-verbal communication in social abilities. Previous research has linked gesture imitation to receptive and expressive vocabulary development [43, 56], and our study further indicated that gesture imitation might have facilitated a broader range of social communication domains beyond vocabulary development. Supporting children in their ability to imitate gestures can help autistic children better understand and engage in non-verbal interactions, which is particularly crucial for children who have difficulties with verbal expression. Moreover, a strong relationship was found between object imitation and joint attention. Imitating others' use of objects might have enhanced or initiated joint attention, which is crucial for social interactions. This finding suggests that facilitating object imitation could promote autistic children's joint attention development.

We further examined how specific imitation factors quantitatively impacted the improvement in social communication skills in autistic children in the context of intervention. Our study was the first to isolate and confirm that two specific imitation factors—improvement in imitation abilities and baseline imitation levels—significantly affected the degree of improvement in social communication skills. The degree of improvement in imitation abilities emerged as a significant predictor of improvements in social communication skills, while baseline imitation levels, although relatively weaker still contributed to the improvement in social communication. Our findings underscore the critical role of imitation in improving social communication skills in autistic children and highlight its importance in the early acquisition of social skills. Previous research on imitation-focused interventions has also shown significant positive effects on social communication skills in autistic children. For example, Reciprocal Imitation Training (RIT) and the Soundbeam Imitation Intervention (SII) have been shown to improve imitation abilities while enhancing related skills such as expressive language and joint attention [12, 18, 19]. Overall, these findings suggest that incorporating supportive imitation practices as a primary goal in early intervention programs for autistic children is both reasonable and beneficial.

We also compared two groups of autistic children receiving different interventions and found that the effects of imitation factors were consistent across both groups, indicating that supporting the development of imitation abilities could be a valuable direction within various intervention strategies. Future research should further explore how to optimize intervention methods to maximize the benefits of supporting children's ability to imitate on social communication skills. Additionally, the specific effects of different forms of imitation (such as gesture, vocal, and object manipulation) in various contexts and their interaction with other cognitive functions merit deeper investigation. Such research will enhance our understanding and support of social communication skills development in autistic children. Finally, regression analysis results showed that the adjusted R^2 values for the ESDM group, the standard intervention group, and the combined dataset were 0.67, 0.46, and 0.48, respectively. It is indicated that imitation factors can explain and predict half of the improvement in social communication abilities in autistic children. Our study aligns with previous findings on the predictive role of baseline imitation levels in social communication development [29, 30] and extends this understanding by offering a quantitative analysis of how imitation factors influence improvements in social communication skills in autistic children.

Age as a moderator

This study was the first to identify that age moderated the relationship between imitation abilities and social communication skills in autistic children. It is suggested that as children grow older, the positive impact of improved imitation abilities on social communication skills becomes increasingly pronounced. This finding offers a new theoretical perspective for understanding the development of social skills in autistic children at different

ages. One possible explanation for this phenomenon is that autistic children who have imitation difficulties may face challenges in acquiring social communication skills, yet their other functions, such as cognitive abilities, continue to develop [51]. Therefore, as they grow, once their imitation abilities improve, the ongoing cognitive and social-emotional development may enable older children to better enhance their social communication skills. Related studies [7]; [48]; Zachor & Ben-Itzchak [54], have also found that autistic children who possess higher cognitive abilities exhibit more significant improvements in social communication following intervention.

Significant effects of ESDM on imitation

Autistic children who received the ESDM intervention showed significant improvements in imitation abilities, although the extent of these improvements varied across individuals. The ESDM group demonstrated gains in the overall imitation score as well as in the subdomains of object imitation, gesture imitation, and oral-facial imitation. These results align with previous studies [49, 52], which have suggested that ESDM intervention can significantly improve imitation skills in autistic children. The positive outcomes observed may be partly attributed to ESDM's core focus on imitation, which is critical for social interaction, emotional resonance, and language development in autistic children [9]. Additionally, the naturalistic teaching strategies used in ESDM, such as following the child's lead, imitating their behavior, and providing prompts and modeling, may further support the development of imitation skills. However, caution is advisable when interpreting the findings of this study, given its non-randomized design. The non-random assignment of participants could result in selection bias, which complicates the assessment of whether the observed enhancements in imitation skills are genuinely a consequence of the ESDM intervention or merely an artifact of the study's design. Despite the absence of parental selection of the intervention approach, the potential for selection bias inherent in the non-randomized nature of the study may limit the external validity and broad applicability of the study's outcomes.

Regarding social communication, numerous previous studies have reported positive outcomes for ESDM, showing its effectiveness in enhancing language [9, 27, 55], social skill [6], and symbolic play skills [48, 55]. In this study, although the ESDM group exhibited improvements in social communication from baseline to post-intervention, with the average improvement greater than the control group, these differences were not statistically significant. This phenomenon may be plausibly accounted for by the moderating effect of age, the relatively younger age of the intervention group may have limited their ability to leverage imitation improvements into substantial gains in social communication, thereby attenuating the observed group differences in social communication outcomes. Another possible reason is that the intervention period in this study was three months, which is relatively short compared to previous studies, such as Dawson et al. [9], who had a two-year intervention period, and Vivanti et al. [48], who had a one-year intervention period. While 12 weeks is the minimum time frame at which measurable effects are typically expected, as indicated in the ESDM manual for the ESDM-CC, it is possible that a longer intervention period may be necessary to observe more substantial and significant improvements in social communication. Additionally, there is heterogeneity in reported social communication outcomes. Fuller et al. [13] conducted a meta-analysis of 12 ESDM intervention studies and noted that, while ESDM has positive effects on social communication in autistic children, there is significant variability in outcomes across different studies. Moreover, imitation ability is not the only factor affecting social communication in autistic children [16, 44]. Although the improvement in imitation abilities was significant, the diversity and complexity of factors influencing social communication could lead to differences in intervention outcomes.

Implications for interventions in autistic children

Imitation and its improvement are strong predictors of enhanced social communication in autistic children, with age serving as a moderating factor. Although age should not be considered in isolation, if imitation abilities remain limited as children grow older, providing targeted interventions to enhance imitation may be an effective strategy for improving social communication skills. Creating additional opportunities for imitative learning within both domestic and educational settings can significantly enhance the support for the development of social communication skills.

Furthermore, the study revealed specific relationship between certain types of imitation and specific social communication skills, such as vocal imitation with expressive communication, gesture imitation with social skills, and object imitation with joint attention. These findings can help practitioners design targeted interventions to strengthen the relevant imitation skills and improve specific social communication abilities.

Finally, the study confirmed the effectiveness of ESDM in improving imitation abilities in autistic children. Given the close link between imitation and social communication, ESDM is particularly well-suited for children with imitation difficulties.

Limitations

This study has several limitations. Firstly, the sample size was relatively small, and due to objective constraints, the

sample was not randomized. Additionally, there were age distribution differences between the experimental and control groups. While this does not affect the conclusion that there is a close relationship between imitation and social communication abilities in autistic children, it may influence the comparative evaluation of the intervention effects. Future research should aim to increase the sample size to improve the generalizability and reliability of the findings, ensuring stricter control of age distribution through random assignment. Furthermore, autism severity should also be considered to provide a more comprehensive understanding.

Secondly, while this study aimed to comprehensively analyze the impact of imitation on social communication in autistic children through an intervention experiment, the short intervention duration and the lack of follow-up evaluation limited the scope of this study. Future research should conduct longitudinal studies over extended periods to further examine the impact of different types of imitation on social communication abilities. This may provide more comprehensive and robust empirical evidence on whether and how imitation can enhance social communication abilities in autistic children in the long term.

Another limitation of this study is its reliance on the ESDM-CC as a measure of social communication. As a proximal measure, the ESDM-CC is designed to capture short-term, intervention-related effects. Although it is well-suited for assessing the immediate effects of a 3-month intervention, it may not capture broader, long-term developmental progress. Future research should incorporate distal measures that assess wider developmental changes over an extended period [39], offering a more comprehensive understanding of children's progress.

Finally, demographic information such as family income and education levels were not collected, and all participants were recruited from urban areas. Therefore, the findings may not fully represent rural or socioeconomically diverse populations, limiting the generalizability of the results. Given the nonrandomized design, there may be differences between groups on these demographic variables that could influence the observed outcomes; however, this cannot be further explored due to the lack of relevant data. Future studies should aim to collect more comprehensive demographic information and include participants from diverse socioeconomic backgrounds to better understand the impact of these factors.

Conclusion

Our findings indicated a strong positive correlation between imitation abilities and social communication skills in autistic children. There were close associations between different types of imitation (object imitation, sound imitation, and gesture imitation) and social communication domains (joint attention, expressive communication, and social skills). The degree of improvement in imitation and baseline imitation levels were key factors influencing the enhancement of social communication skills, with the degree of imitation improvement being the strongest predictor. Furthermore, age moderated the relationship between imitation improvement and social communication skills enhancement. Our study also corroborated that the ESDM significantly enhanced imitation abilities in autistic children. Therefore, our research confirms the importance of imitation in various dimensions of social communication. By improving imitation abilities, it may effectively promote enhancement in social communication for autistic children, with the ESDM being a potentially effective intervention to achieve this goal.

Author contributions

JL conceptualized the whole study. SX and JL jointly designed the study. JL got the funding. SX collected the data and performed the data analysis. SX wrote the first draft of the manuscript, while JL reviewed and revised the manuscript. Both authors have read and approved the final version of the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the Institute of Psychology, Chinese Academy of Sciences Child Subjects Committee and was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from the parents or guardians of children.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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