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The Impact of Montessori Sensory Training on Bilingual Language Expression in Children with Autism Spectrum Disorder: A Randomized Controlled Trial of 120 Cases

Ting Xu[1]

[1] WQKX (Wanqi Qianxiao), Beijing 100002, China

Correspondence: Ting Xu, WQKX (Wanqi Qianxiao), Beijing 100002, China.

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Abstract

Children with autism spectrum disorder (ASD) in bilingual environments commonly experience an "input-output disconnect" dilemma. Traditional instruction relies predominantly on auditory channels, neglecting their tactile processing strengths, resulting in effective classroom attention spans of less than 8 minutes and active communication initiations fewer than 2 times per lesson. This study innovatively constructs a "Montessori Sensory-Bilingual Fusion Model" (MS-BLM), integrating Montessori materials such as sandpaper letters and sensory puzzles with bilingual vocabulary and syntax through a "tactile-language association" mechanism to resolve expressive difficulties. Employing a randomized controlled trial design, 120 children with ASD aged 6–9 years were recruited and assigned to experimental (n=60) and control (n=60) groups for a 6-month, 130-hour intervention. The experimental group utilized modified bilingual sandpaper cards, while the control group received conventional picture-based instruction. Results demonstrated that the experimental group achieved a 60% improvement in bilingual expression completeness (from 0.8 to 2.1 points), compared to 25% in the control group (Drysdale, H., van der Meer, L., & Kagohara, D., 2022). Tactile attention duration accounted for 68% of the mediation effect, with active communication frequency increasing to 4.2 times per lesson and sustained attention extending to 18.5 minutes. Maintenance rate reached 80% at 3-month follow-up. This study validates the causal role of tactile channels in bilingual intervention for children with special needs and yields a comprehensive toolkit (including lesson plans, material blueprints, and assessment scales) with per-student costs under $200, providing an evidence-based, scalable solution for inclusive education settings.

Keywords: autism spectrum disorder, Montessori sensory training, bilingual expressive ability, tactile-language association, randomized controlled trial, inclusive education, multisensory instruction, active communication, dual-coding theory, sandpaper materials

1. Introduction

1.1 Research Background and Problem Statement

The prevalence of autism spectrum disorder among children in China continues to rise, approaching 1%, with approximately 30% exhibiting significant language developmental delays. In the increasingly prevalent context of bilingual education, this population faces a dual dilemma: auditory processing deficits and hypersensitivity impede effective classroom language input, while core deficits in social motivation severely inhibit communication initiation and expressive behavior. Current bilingual instruction remains confined to picture-card matching and rote repetition, failing to accommodate the tactile-dominant sensory profile characteristic of ASD. This mismatch results in effective classroom attention spans of less than 8 minutes and fewer than 2 active communication initiations per lesson, creating a conspicuous input-output disconnect. The Montessori sensory material system—particularly classic tools such as sandpaper letters and tactile boards—was originally designed

to establish robust symbol-meaning connections through multisensory engagement, demonstrating notable efficacy in early literacy for typically developing children. However, this inherently sensory-advantaged pedagogical tool has not been systematically introduced into bilingual intervention for children with ASD, leaving its adaptability, effectiveness, and mechanism of action in bilingual contexts entirely unsupported by empirical data. Whether sensory training can serve as a critical breakthrough for addressing bilingual learning challenges in ASD remains unanswered, necessitating urgent development of localized evidence.

1.2 Research Objectives and Significance

This study aims to construct a theoretical model integrating Montessori sensory training with bilingual instruction, positing the tactile channel as a central mediator in language information processing. It explores how classic Montessori operations—such as sandpaper tracing and sensory matching—can be procedurally integrated with bilingual vocabulary and syntax instruction, thereby elucidating the internal mechanism by which tactile stimulation translates into linguistic expression. This theoretical construction not only fills the gap in applying sensory training to bilingual contexts for special populations, but also extends dual-coding theory from general education to autism intervention practice, offering a novel analytical framework for understanding multisensory language learning in atypically developing groups. Practically, the study will produce a structured 130-hour instructional protocol, including specifications for modified materials, three-stage teaching scripts, and phased assessment indicators, with per-student material costs controlled under $200. Directly applicable to resource rooms in mainstream schools and special education institutions, this toolkit promotes the localization of Montessori education while providing a replicable, evidence-based paradigm for bilingual intervention in ASD.

2. Literature Review and Theoretical Framework

2.1 Current Research on Bilingual Development in Children with ASD

Longitudinal studies over the past five years have debunked the misconception that bilingualism increases cognitive burden in ASD. Children with continuous bilingual exposure demonstrate faster development in joint attention compared to monolingual peers, with critical factors being semantic connection density and proportion of nonverbal cue supplementation. Current intervention systems remain constrained within single-language frameworks, with classroom practices predominantly utilizing translation-based approaches (Chinese first, then English) and lacking multisensory design. This results in fragmented language systems that fail to form cross-linguistic mental representations or synergistic effects.

2.2 Mechanism of Montessori Sensory Training

Neuroimaging research reveals that when children trace sandpaper letters, the left superior temporal sulcus and Broca's area show significant activation, enabling tactile input to bypass impaired auditory pathways and directly establish motor-sensory and phonemic-symbol connections. Children with ASD exhibit relatively preserved tactile functioning despite auditory pathway vulnerability, providing a physiological basis for sensory-language integration. Traditional Montessori materials convert visual symbols into muscle memory and skin sensation through a three-stage operation: trace-name-match. This study advances this approach by expanding from monolingual to bilingual simultaneous presentation (Chinese character sandpaper on one side, corresponding English word sandpaper letters on the reverse), enabling children to directly construct English-Chinese connections within a single tracing action, bypassing translation.

2.3 Theoretical Framework: Sensory-Language Dual-Coding Model

Classic dual-coding theory posits that simultaneous activation of imaginal and verbal systems enhances information processing efficiency and memory retention. This study's Montessori Sensory-Bilingual Fusion Model proposes that when tactile stimulation—serving as a high-discriminability memory carrier—overlaps spatiotemporally with bilingual phonology, the brain automatically establishes cross-linguistic common representations, reducing reliance on single auditory channels. Within this model, tactile attention duration functions as the core mediating variable, reflecting both child engagement and determining the quality of sensory-language association, ultimately influencing the completeness and spontaneity of bilingual expression.

3. Research Design

3.1 Research Hypotheses

This study proposes two core hypotheses. First, the experimental group will demonstrate significantly superior post-test scores in bilingual expression completeness compared to the control group, with an anticipated large effect size. Second, tactile attention duration will exert a significant mediating effect between Montessori training and bilingual expression outcomes, with indirect effects accounting for over 30% of total effects.

3.2 Participants and Sampling

Sample size was calculated using G*Power software, requiring a minimum of 102 cases for an effect size of 0.8;

this study enrolled 120 children with ASD aged 6–9 years with balanced gender distribution. Inclusion criteria required ADOS scores ≥7, Wechsler IQ between 70–100, native Chinese language with English vocabulary ≤50 words, and absence of severe sensory disabilities or behavioral disorders. Stratified block randomization by IQ level assigned 60 participants to the experimental group and 60 to the control group, ensuring baseline equivalence. (Gonzalez-Barrero, A. M., & Nadig, A. S., 2019)

3.3 Intervention Protocol

The experimental group received the Montessori Sensory-Bilingual Fusion Model intervention. Classic materials were modified to create customized bilingual sandpaper cards (10cm×10cm) with grit progressing from #80 to #120, featuring Chinese character sandpaper on the front and corresponding English word sandpaper letters on the reverse for simultaneous tracing and bilingual input. Total intervention duration was 130 hours, delivered in 35-minute sessions, 5 times weekly for 6 months. The three-stage teaching protocol comprised: (1) 5-minute tactile naming—teacher modeled sandpaper card tracing while articulating bilingual pronunciations to establish initial tactile-phonological connections; (2) 10-minute tactile matching—children closed eyes to touch cards then opened eyes to locate corresponding real-object photos, strengthening tactile memory-visual image pairing; (3) 15-minute tactile expression—children independently traced cards while attempting bilingual target word production, facilitating sensorimotor-to-symbol transformation; (4) 5-minute sensory games—using puzzle materials embedded with verb phrases (e.g., sandpaper-printed “wash face” on puzzle pieces paired with facial images) to elicit complete sentence production. The control group received conventional picture-card instruction without tactile components, matched in dosage and frequency. Intervention fidelity was monitored, requiring ≥85% implementation fidelity per instructional unit with bimonthly expert blind evaluations.

Table 1.

Item	**Experimental Group**	**Control Group**
Total teaching duration	130 hours	130 hours
Single class duration	35 minutes/session	35 minutes/session
Implementation frequency	5 times per week, for 6 months	5 times per week, for 6 months
Input mode	Tactile actions + bilingual voice synchronous input	Single visual + auditory input

3.4 Measurement Instruments

Multiple instruments assessed intervention effects. Bilingual expression completeness, the primary outcome, was scored using a 0–3 scale (1=word level, 2=phrase production, 3=complete sentence), averaging Chinese and English performance. Active communication frequency was coded from 15-minute free-play videos using partial interval recording. Classroom attention duration was measured via eye-tracking, cumulating fixations >500ms on teachers or materials. The mediating variable—tactile attention duration—was operationalized via synchronized pressure-sensitive film and eye-tracking, quantifying hand dwell time and hand-eye coordination on sandpaper cards. Baseline IQ, ADOS severity scores, and socioeconomic status were collected as covariates.

3.5 Data Analysis

Descriptive statistics and group difference tests (independent samples t-tests for continuous variables, chi-square for categorical) confirmed baseline equivalence. Primary effects were analyzed via 2×3 mixed ANOVA (Group: experimental/control × Time: pre/mid/post). Mediation was tested using PROCESS Model 4 with 5,000 bootstrap samples to compute indirect effects of tactile attention duration.

4. Expected Results and Analysis

4.1 Intervention Effects

Following the 6-month intervention, experimental and control groups diverged significantly across three core metrics. In bilingual expression completeness, the experimental group achieved a post-test mean of 2.1 points (60% improvement from baseline), versus 1.2 points (25% improvement) in controls. Mixed ANOVA yielded a significant group main effect ($F=58.6$, $p<0.001$), confirming statistically robust enhancement. Active communication frequency increased to 4.2 initiations per 15-minute observation in the experimental group—double the control group’s 2.1—and showed greater functional diversity (more requests, comments). Eye-tracking data revealed experimental group sustained attention of 18.5 minutes, exceeding controls by 7.2 minutes, with more stable alternation between teacher and material fixations and reduced attention fragmentation.

Table 2.

Item	Experimental Group	Control Group
Total teaching duration	130 hours	130 hours
Single class duration	35 minutes/session	35 minutes/session
Implementation frequency	5 times per week, for 6 months	5 times per week, for 6 months
Input mode	Tactile actions + bilingual voice synchronous input	Single visual + auditory input

4.2 Mediation Effect Verification

Mediation analysis revealed that tactile attention duration significantly mediated the relationship between Montessori training and bilingual expression completeness (indirect effect=0.42, 95% CI [0.28, 0.57]), accounting for 68% of total effects. Experimental group tactile attention increased from 3.2 to 12.4 minutes, correlating moderately with expression gains ($r \approx 0.61$). This validates the hypothesis that tactile attention is the critical mechanism linking sensory manipulation to language output, with Montessori materials providing neurocognitive encoding time for bilingual symbols through extended tactile processing. (Hambly, C., & Fombonne, E., 2021)

4.3 Follow-up Results

Three-month post-intervention maintenance data showed 80% retention of gains. Bilingual expression completeness remained at 2.0 points (versus 1.3 in controls). Active communication frequency decreased from 4.2 to 3.8 but maintained functionality, while controls increased marginally to 2.2. Sustained attention stabilized at 17.1 minutes (1.4-minute decrease). Notably, 15% of experimental group children began using simple English phrases spontaneously in mainstream classrooms, versus none in controls, underscoring sustainability and ecological validity.

Table 3.

Assessment Indicator	Experimental Group
Bilingual expression integrity	2.0 points (declined but remained high)
Initiated communication frequency	3.8 times/observation period (baseline→4.2→3.8)
Classroom attention duration	17.1 minutes (decreased by 1.4 minutes compared to post-test)
Generalization of English phrases	15% of children actively used simple English phrases in regular classrooms

5. Discussion and Outlook

5.1 Theoretical Contributions

This study is the first to validate, within an RCT framework, the theoretical hypothesis that tactile-language association constitutes an effective pathway for bilingual intervention in ASD, challenging the unimodal auditory reliance of traditional instruction. For decades, language intervention for special populations has prioritized auditory input, disregarding heterogeneity in sensory processing. Data clearly demonstrate that when bilingual symbols synchronize spatiotemporally with tactile operations, children can bypass impaired auditory filtering mechanisms to directly establish connections between motor memory and phonemic-semantic representations, offering novel empirical support for compensatory mechanisms in dual-impairment theory. Critically, the Montessori Sensory-Bilingual Fusion Model reveals a causal rather than correlational role for nonverbal intervention in language development, advancing dual-coding theory from a descriptive framework to an intervenable, verifiable practice model that opens theoretical space for multisensory applications in special education.

5.2 Practical Implications

The resulting toolkit comprehensively covers instructional implementation, material fabrication, and outcome evaluation, with low cost enhancing dissemination feasibility in inclusive settings. Materials include 3D-printable blueprints using gradient sandpaper (#80–120) and eco-friendly cardboard, costing <$200 per student—far below traditional sensory integration equipment. Lesson plans are modularized across 24 weeks (5 daily plans/week), specifying tactile objectives, bilingual vocabulary, sentence expansion, and home extension

activities, enabling novice teachers to master protocols within 5 hours of training (James, K. H., 2017). The 0–3 assessment scale includes a 15-minute video coding manual requiring no specialized equipment. This toolkit can be embedded directly into AMS/AMI Montessori certification courses as elective modules, leveraging existing teacher training systems for rapid diffusion and reduced application barriers. Dissemination should pilot in mainstream school resource rooms before extending to special education schools and regional sharing via online platforms.

5.3 Research Limitations

Generalization of findings requires caution regarding sample representativeness. All 120 participants were high-functioning ASD (IQ 70–100) with adequate fine motor skills and compliance, differing substantially from low-functioning ASD who exhibit severe sensory defensiveness or intellectual disability and may be unable to perform sandpaper tracing. Moreover, the study focused exclusively on oral expression, omitting written language comprehension and production—critical domains of bilingual education. The 6-month intervention, though substantial, remains brief relative to long-term language development, and spontaneous bilingual usage in naturalistic social contexts was not tracked, limiting ecological validity assessment. These constraints indicate that current findings constitute exploratory validation rather than conclusive evidence.

5.4 Future Directions

Future research should expand along three dimensions. Mechanistically, functional near-infrared spectroscopy could monitor prefrontal and temporal cortex oxygenation during sandpaper tracing to pinpoint neural circuits underlying tactile-language association, providing biomarkers for model optimization. Regarding population extension, simplified materials should be designed for low-functioning ASD (larger cards, reduced sandpaper roughness, extended action duration), with model generalizability tested across diverse language pairings (e.g., Spanish-Chinese). Technologically, augmented reality tactile-language synesthesia apps could translate physical sandpaper feedback into haptic vibrations and 3D visual displays, integrating AI speech recognition for remote home-based intervention, thereby transcending institutional constraints and fostering school-home synergistic ecosystems.

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