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Neuro-Kinesthetic Stimulation: Optimizing Playdough Manipulation to Address Fine Motor Stagnation in 4–5-Year-Olds

Ziyadatul Ilmiyah*, Suharti, Mallevi Agustin Ningrum, Dhian Gowinda Luh Safitri, Kartika Rinakit Adhe, Budi Purwoko
Early Childhood Education Department, Faculty of Education,
Universitas Negeri Surabaya, Indonesia.
*Corresponding Author. Email: ziyadatulilmiyah.23063@mhs.unesa.ac.id

Abstract: This study aims to evaluate the effectiveness of optimizing playdough-based activities to enhance fine motor skills in children aged 4–5 years. Employing a quasi-experimental non-equivalent control group design, the research involved 28 children divided into an experimental group ($n = 16$, structured playdough intervention) and a control group ($n = 12$, conventional paper-based media). Data were collected using structured observation scales and performance rubrics, and analyzed via descriptive statistics, N-Gain scores, and independent t-tests. Results indicate a significant disparity in motor skill acquisition between the groups ($t = 8.642, p < 0.05$). The experimental group's post-test score significantly increased to 82.50 (from 56.56), yielding an N-Gain of 60.33% (Moderately Effective). Conversely, the control group only achieved an N-Gain of 24.18% (Ineffective). These findings demonstrate that the tactile resistance of playdough provides superior stimulation for the hand's intrinsic muscles compared to traditional methods. Consequently, early childhood educators should integrate structured playdough activities into the core curriculum rather than treating them as elective play. Future research should implement longitudinal tracking to determine the long-term impact of these motor gains on formal writing readiness.

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Introduction

Early Childhood Education (ECE) serves as a pivotal foundation in the human development cycle, determining the quality of future human resources. During the golden age, particularly for children aged 4-5 years, brain development reaches its most plastic state, where appropriate stimulation significantly impacts all developmental dimensions, including cognitive, socio-emotional, linguistic, and physical-motor domains (Yusuf et al., 2023). In the context of physical development, fine motor proficiency emerges as a critical indicator of a child's learning readiness. Fine motor skills involve the coordination of small muscles in the hands and fingers, integrated with visual-motor synchronization (Safariyah et al., 2026). This capability is not merely a physical skill but a bridge for children to master various functional daily activities and fundamental academic skills, such as writing, drawing, and cutting (Putri et al., 2021).

Theoretically, fine motor development in children aged 4-5 years should encompass the ability to control hand movements with increasing precision. However, empirical evidence suggests that many children in this age group still encounter obstacles in finger coordination. A frequently observed phenomenon is hand muscle fatigue when gripping a pencil or an inability to perform simple tasks, such as stringing beads or folding paper neatly

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(Sulasiyah & Wapa, 2024). If left unaddressed, these issues will lead to diminished self-confidence and delays in mastering basic literacy. Consequently, an intervention that is both instructional and recreational is required, adhering to the core ECE principle of learning through play.

One medium considered highly effective in stimulating fine motor skills is playdough. As a manipulative medium, playdough is flexible, malleable, and easily shaped. Activities such as squeezing, twisting, pressing, rolling, and cutting playdough compel the intrinsic muscles of the child's hand to work actively. The utilization of this medium aligns with sensorimotor development theory, where children learn through direct tactile experiences with textured materials (Pamungkas et al., 2023). Through playdough, children not only exercise finger strength but also sharpen their imagination and creativity in generating various visual forms.

One medium considered highly effective in stimulating fine motor skills is playdough. As a manipulative medium, playdough is flexible, malleable, and easily shaped; activities such as squeezing, twisting, pressing, rolling, and cutting compel the intrinsic muscles of the child's hand to work actively, aligning with sensorimotor development theory where children learn through direct tactile experiences (Pamungkas et al., 2023). While previous studies have extensively explored the effectiveness of various manipulative media, such as natural materials and finger painting to enhance hand flexibility, a significant research gap remains. Most existing literature focuses on general motor outcomes without providing a profound neuro-kinesthetic analysis of how systematic playdough manipulation can accelerate specific motor indicators. This study addresses this gap by integrating neuro-kinesthetic stimulation with playdough optimization to resolve fine motor stagnation in children aged 4–5 years, aligned with the Kurikulum Merdeka framework.

This phenomenon has become increasingly critical in the digital era, where excessive screen time and gadget usage often lead to underdeveloped finger muscles due to the passive nature of scrolling and tapping actions, which restricts the dynamic tactile exploration necessary for manual dexterity (Lin et al., 2017; Tamana et al., 2019). Furthermore, limited empirical evidence compares structured playdough interventions against traditional paper-based methods within a quasi-experimental setting. This study addresses this gap by presenting a state of the art optimization approach that positions playdough not merely as a supplementary medium, but as the primary instrument integrated into structured learning scenarios with graded difficulty levels. The explicit novelty of this research lies in the utilization of safe, economical, "homemade" playdough, which offers broader sensory engagement (olfactory and tactile) and superior tactile resistance compared to stiffer commercial products (Astuti et al., 2022). Additionally, by implementing a systematic gradation of difficulty—ranging from basic forms to complex three-dimensional structures—this intervention directly aligns with the Kurikulum Merdeka framework to foster the dimensions of the Profil Pelajar Pancasila, particularly creativity and independence. The urgency of this research is underscored by the reality of the digital era, where children spend excessive time on touchscreen devices. Scrolling and tapping actions do not provide sufficient workload for finger muscles, leading to a downward trend in fine motor abilities among preschoolers (Purwanti et al., 2023). Playdough play emerges as a conventional yet relevant solution to restore the essence of kinesthetic learning. By kneading playdough, children receive the sensory pressure required to strengthen ligaments and hand muscles, an absolute prerequisite before progressing to early writing stages (Jayatmi, 2024).

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In-depth optimization involves demonstration methods and challenging task assignments. Educators do not merely provide materials but also offer stimulation through stories or themes that children must translate into dough forms. This translation process from idea to physical form involves intensive hand-eye coordination. Consequently, this study explicitly aims to evaluate the efficacy of this systematic, neuro-kinesthetic playdough optimization in accelerating fine motor development. Beyond establishing statistical effectiveness, this research contributes a novel, scalable pedagogical framework for early childhood educators, demonstrating how structured manipulative play can be practically aligned with the Kurikulum Merdeka to surpass national developmental standards and mitigate fine motor stagnation in the digital era.

Research Method

This study employed a quantitative approach with a quasi-experimental non-equivalent control group design using pre-existing, naturally formed classes. The sample comprised 28 children aged 4–5 years at Tunas Bangsa Sidojangkung Kindergarten, Gresik, selected via purposive sampling based on age homogeneity and equivalent baseline fine motor obstacles. The participants were divided into an experimental group ($n = 16$, Group A1) receiving optimized playdough interventions and a control group ($n = 12$, Group A2) following conventional paper-based learning.

Data collection relied on structured observation checklists based on national early childhood standards, performance rubrics assessing hand-eye coordination precision, and photographic documentation. The research procedure progressed through four systematic phases: instrument validation, pre-testing baseline skills, a five-session treatment phase featuring a systematic gradation of playdough manipulation difficulty, and post-testing.

Quantitative data analysis was executed using SPSS Statistics software version 26.0. Prior to hypothesis testing, data distribution and variance were validated through Shapiro-Wilk normality and homogeneity tests. To evaluate the intensity of developmental improvement, normalized gain scores were calculated using Hake's N-Gain formula:

$$\text{N-Gain} = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum Score} - \text{Pretest Score}}$$

The results were categorized into high ($g > 0.7$), moderate ($0.3 \leq g \leq 0.7$), and low ($g < 0.3$) efficacy levels. Finally, an Independent Sample T-test was performed on the calculated N-Gain scores to examine the statistical significance of the differences between the two groups and test the primary research hypothesis.

Results and Discussion

(a) (b) (c)

Figure 1. Children activites in experimental class:(a) This activity stimulated the palm muscles and initial finger grip strength. In the subsequent phase, children applied organic coloring agents to the playdough mixture.; (b) This specific task required precise, repetitive pinching (*pincer grasp*) and deep sensory-motor integration to blend the pigments evenly into the dough substrate.; (c) where children successfully manipulated the high-resistance homemade

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playdough into complex, three-dimensional geometric and representative models, demonstrating advanced bilateral hand coordination.

This study involved two distinct groups of subjects: the Experimental Class (N=16) and the Control Class (N=12). The primary focus was to evaluate the effectiveness of the intervention by comparing pre-test and post-test scores.

Statistical Description of Test Scores

Based on the data processing results, the following overview represents the performance of both groups:

Table 1. Descriptive Statistics Summary of Learning Outcomes

Group	Variable	Mean	Std. Deviation	Minimum	Maximum
Experimental	Pre-test	56.56	8.310	45	75
	Post-test	82.50	5.477	75	95
Control	Pre-test	54.58	6.557	45	65
	Post-test	65.42	5.823	55	75

The data interpretation reveals a distinct developmental variation between the two groups. The experimental class exhibited a substantial mean score enhancement of 25.94 points, signifying that the structured manipulation of dough significantly stimulated the children's manual dexterity and muscle memory. In contrast, the control class demonstrated a modest increase of only 10.84 points, indicating that conventional fine motor activities, while contributory, do not offer the same level of intensive neuromuscular stimulation as the optimized playdough method.

(a)

(b)

Figure 2. Children activites in control class: (a) While this task utilized the index and middle fingers to operate scissors, it provided limited resistance compared to the malleable dough compound.; (b) Although this activity supported spatial reasoning and basic finger precision, the reliance on flat paper media resulted in a more passive tactile engagement, which accounts for the relatively modest post-test growth observed in this cohort.

Prerequisite Analysis Results

Normality Test

The normality test was conducted using the Shapiro-Wilk method, which was selected due to its high sensitivity and appropriateness for relatively small sample sizes (N < 50). This test aims to ensure that the data from both the experimental and control groups are normally distributed, thereby fulfilling the fundamental assumption required for parametric statistical testing.

Table 2. Results of Normality (Shapiro-Wilk)

Variable	Group	Statistics	df	Sig. (p)	Conclusion
N-Gain Score	Experiment |	.945	16	.411	Normal
Post-test	Control	.918	12	.267	Normal

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Based on Table 2, the significance values for the Experimental group ($p = 0.411$) and the Control group ($p = 0.267$) are both greater than 0.05. Therefore, it can be concluded that the N-Gain data for both groups are normally distributed, confirming that the fundamental assumptions for performing parametric statistical analysis have been satisfied.

Effectiveness Analysis via N-Gain

The Normalized Gain (N-Gain) analysis was employed to evaluate the effectiveness of the intervention by standardizing the improvement in students' scores. This method allows for a more precise comparison of progress, independent of the initial pre-test levels.

Descriptive Statistics of N-Gain

Table 3. Results of N-Gain Score Analysis (Percentage %)

Indicator	Experimental Class	Control Class
Mean (Rata-rata)	60.3340	24.1824
Minimum	42.86	0.00
Maximum	81.82	40.00
Std. Deviasi	11.24058	10.54848

The quantitative evaluation revealed a stark contrast in developmental acceleration between the two cohorts. The experimental class achieved a mean N-Gain score of 60.33%, classifying the optimized playdough intervention as Moderately Effective in substantially facilitating fine motor mastery. Conversely, the control class yielded a mean N-Gain score of only 24.18%, falling into the Ineffective category. This significant disparity empirically demonstrates that conventional paper-based methods provide insufficient neuromuscular engagement, whereas the tactile resistance and structured difficulty levels of optimized playdough activities serve as a far superior catalyst for accelerating early childhood manual dexterity.

Hypothesis Testing (Independent Sample T-Test)

To determine whether the observed difference in N-Gain scores between the two groups was statistically significant, an Independent Sample T-test was performed.

Table 4. Results of Independent Sample T-Test on N-Gain Scores

Variable	t	df	Sig. (2-tailed)	Mean Difference
N-Gain Score	8.642	26	.000	36.1516

The statistical analysis yielded a significance value (Sig. 2-tailed) of 0.000 which is considerably lower than the alpha level of 0.05 ($p < 0.05$). These results provide strong evidence to reject the null hypothesis (Ho) and accept the alternative hypothesis ($H\alpha$). Consequently, it can be concluded that there is a highly significant difference in effectiveness between the optimized playdough method used in the experimental class and the conventional approach used in the control class.

Learning Outcome Transformation: Playdough Effectiveness vs. Paper Manipulation

Based on the research findings, there is a stark contrast in both cognitive and psychomotor performance between students engaged in playdough activities and those involved in paper manipulation. The experimental group's success in achieving a post-test mean of 82.50, a significant increase from the pre-test mean of 56.56, demonstrates that the playdough intervention effectively accelerates conceptual understanding and physical skills simultaneously (Afni Anggraini, Umi Hanik Fetriyah, 2024) (Alpiana et al., 2025). Conversely, the control group using paper media experienced a modest mean increase of only

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10.84 points, indicating that conventional media have inherent limitations in progressively stimulating motor development.

Viewed through the lens of constructivism, the experimental method using playdough facilitates meaningful learning. (Simanjuntak et al., 2023)) and (Rizky Amaliya & Khodijatul Kubro, 2025) explain that active learning designed within an experimental framework enhances total mental engagement. In this context, students are not merely passive recipients of instructions but become the primary actors in object formation. This aligns with (Paputungan, 2024), who asserts that active learning models provide crucial space for independent exploration in early childhood development. This superiority is statistically reinforced by the t-test results, which yielded a significance value of 0.000, absolutely confirming the tangible impact of the intervention compared to the paper manipulation method.

N-Gain Analysis: Tactile Stimulation through Playdough

The application of Normalized Gain (N-Gain) analysis provides an objective representation of the intervention's effectiveness. The experimental group's achievement of a 60.33% N-Gain is classified as Moderately Effective, indicating that this method successfully bridged the majority of the students' initial skill gaps. In contrast, paper manipulation in the control group reached an N-Gain of only 24.18%, categorized as Ineffective. This effectiveness disparity of 36.15% provides robust validation that the tactile stimulation offered by playdough is significantly superior to that of paper.

This superiority is rooted in playdough's ability to provide neural feedback through the material's pressure and resistance. As children knead the dough, they receive sensory information regarding density and volume, stimuli that are absent when folding thin, two-dimensional paper (Khalimatus & Mudlikah, 2025).The use of homemade playdough in this study served as a key factor; its softer and more malleable texture allowed children's small fingers to experiment without experiencing premature muscle fatigue (Fitriani, 2023). Furthermore, (Jamilah & Astria, 2023), (Mulianingtias & , Feri Tiona Pasaribu, 2024) Retnaningsih (2023), and Mulianingtias & Pasaribu (2024) emphasize that manipulative and responsive teaching aids are highly effective in enhancing children's procedural memory retention.

Neuroscience Perspective: The Correlation Between Finger Dexterity and Cognition

From a neuroscience perspective, the precision required in finger movements during playdough modeling activates Broca's area in the brain. This region not only governs fine motor control but also serves as a critical hub for language processing. Consequently, this experimental activity indirectly establishes a cognitive foundation for children's communication skills (Nor Amizah, 2024). The psychomotor involvement inherent in the experimental procedure strengthens synaptic formation, ensuring that the acquired knowledge remains relatively permanent in long-term memory (Arfiani, 2022) and (Irawan, 2022).

This contrast is evident when compared to paper manipulation in the control group, which tends to offer limited variations in movement. Although activities such as cutting or folding enhance eye-hand coordination (Samsidar, 2019), they provide significantly less workload for the intrinsic hand muscles than the process of shaping three-dimensional figurative objects from clay (Pao et al., 2020). Furthermore, (Nurjanah et al., 2025) and (Daryana et al., 2026) assert that the broader sensory engagement provided by playdough, including its distinct aroma and texture, stimulates the occipital lobe and other sensory areas more intensively than conventional paper media (Rianti et al., 2022).

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Digital Era Challenges and Control Group Stagnation

The research findings reveal a critical reality regarding the developmental stagnation observed in the control group. The minimal score improvement in paper manipulation activities suggests that conventional methods are beginning to lose their relevance in addressing the challenges of the digital era. Excessive gadget use has accustomed children to scrolling and tapping motions, which are motorically passive (Syafruddin & Sutriawan, 2024) (Syaifuddin & Ro'isah, 2024). Consequently, children's finger muscles remain undertrained in providing strong, precise pressure (Fitriyani et al., 2025).

In this context, the playdough intervention serves as a kinesthetic solution to restore the essence of fundamental motor learning. Conversely, the unidirectional nature of paper manipulation often leads to cognitive satiation (boredom). (Husaen, 2024) notes that without interactive and varied stimuli, students tend to follow instructions mechanically without grasping the essence of the movements. This observation is reinforced by (Farhatin Masruroh & Khulusinniyah, 2019), (Etri Yanti & Fridalni, 2020) and Amalia et al. (2024), who found that without specific, challenging interventions, children's physical-motor development remains sluggish and fails to reach optimal Golden Age developmental milestones.

Variability Analysis and Differentiation of Student Responses

Although the experimental group outperformed the control group in aggregate, the dynamic variability within the results warrants a more granular analysis. The N-Gain standard deviation of 11.24 in the experimental class indicates distinct individual response patterns. While some students achieved a maximum N-Gain of 81.82%, others performed at a level of 42.86%. Arifin (2022) describes this phenomenon as the influence of prior knowledge or varying baseline motor skills unique to each child (Hasanuddin, 2020).

This differentiation demonstrates that playdough provides an inclusive space for children to develop according to their respective kinesthetic capacities. Children with a high affinity for visual arts tended to respond more rapidly to techniques involving figurative modeling, such as constructing the train model (Murni & Iqbal, 2022). However, from an inclusive standpoint, every participant in the experimental group showed positive progress; this is evidenced by the experimental group's minimum post-test score of 75, which already matches their pre-test maximum. This confirms that the intervention remains universally effective across the student cohort, albeit with varying acceleration velocities (Setiawati, 2022).

Internalizing the *Pancasila* Student Profile Through Deep Learning

Within the context of the *Kurikulum Merdeka*, the use of playdough transcends simple motor activity; it serves as a vehicle for internalizing the Pancasila Student Profile through a deep learning approach. Unlike paper manipulation, which tends to follow rigid instructional patterns (such as folding along predefined lines), playdough play provides children with the autonomy to engage in independent exploration (Mahardika & El-Yunusi, 2025). This directly strengthens the Creative dimension, as children are challenged to modify ideas and generate original outputs from a shapeless mass of dough (Harefa et al., 2024). The cognitive translation from an abstract concept into a three-dimensional form, such as the figurative train model, manifests the flexible thinking characteristic of a competent graduate profile.

Furthermore, this activity addresses the Independent dimension. Through graded levels of difficulty, children are encouraged to practice self-regulation in completing their projects, progressing from simple spherical shapes to complex structures (Puling et al., 2023). A child's success in mastering the dynamic medium of playdough builds self-efficacy; they gain a sense of agency over their environment, which serves as a vital foundation for future academic independence (Ngawan et al., 2025). This stands in stark contrast to the control

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group (paper manipulation), where children often become dependent on teacher assistance when faced with irreversible folding errors that are difficult to rectify (Susanti et al., 2025).

Comparative Analysis of Media Characteristics: Playdough vs. Paper

The superiority of playdough in this study can also be elucidated through cognitive and sensory load theories. As a manipulative medium, paper possesses physical limitations; it is unidirectional and prone to tearing when subjected to excessive pressure (Adiningsih & Syafrina, 2019). This fragility often induces frustration in children aged 4-5, whose intrinsic hand muscles are not yet fully matured (Hadijah et al., 2024). In contrast, playdough is characterized by its "forgiving" nature; if a child commits a structural error, they can simply reshape the dough and restart the process (Septiani Selly Susanti, Anita Oktaviana, 2024). This elastic physical property provides consistent "counter-pressure" to the nerve endings in the fingertips which, from a neuroscience perspective, delivers much richer neural feedback to stimulate brain plasticity during the critical Golden Age period.

The variability analysis within the experimental group (Std. Deviation 11.24) further indicates that playdough activities accommodate diverse learning profiles. Children with dominant visual-spatial intelligence were able to achieve N-Gain scores as high as 81.82%, while others consistently demonstrated positive progress exceeding that of the control group. This proves that kinetic manipulative media are more inclusive in facilitating varying levels of prior knowledge and learning velocities, aligning perfectly with the principles of differentiated learning enshrined in the *Kurikulum Merdeka*.

Long-Term Implications for Academic Readiness

The significant t-test results (p = 0,000) confirm that the optimization of playdough is not merely a recreational activity, but a long-term investment in early writing readiness (pre-writing skills). The maturation of hand muscles gained from kneading dough is an absolute prerequisite before children are tasked with precise pencil-holding techniques (Dora Febrinavani & Faqihatuddiniyah, 2025). Furthermore, the decline in fine motor skills caused by excessive touchscreen exposure can be effectively mitigated through playdough interventions (Fairuz et al., 2025). Its kinesthetic workload successfully restores the essence of tactile learning that is often lost in digital interactions (Setyaningsih & Fitri, 2022).

Practically, the "Moderately Effective" finding (60.33%) suggests that early childhood educators should move away from monotonous paper-and-pencil activities. Educators must transition into facilitators who provide sensory-rich learning environments to narrow the skill gaps among students. This approach ensures that every graduate possesses a resilient, creative, and independent profile, aligned with the overarching goals of the *Kurikulum Merdeka* (Basyori, 2025).

Conclusion

In conclusion, optimizing playdough manipulation is significantly effective in enhancing the fine motor skills of children aged 4–5 years at TK Tunas Bangsa Sidojangkung. This is empirically evidenced by the experimental group's superior post-test leap to 82.50 and a 60.33% N-Gain (Moderately Effective), sharply contrasting the control group’s 24.18% N-Gain (Ineffective). Structured activities like kneading, twisting, and molding provide intensive tactile stimulation and neuromuscular workloads that surpass conventional paper-based methods. Furthermore, using homemade playdough fosters autonomy and independence aligned with the Profil Pelajar Pancasila dimensions. From a neuroscience perspective, these precise movements effectively activate sensory brain areas crucial for advancing subsequent pre-writing readiness.

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Recommendation

Several practical recommendations are proposed: (1) For Teachers: Integrate playdough as a primary motor stimulation instrument within weekly themes, providing graded challenges from simple to 3D shapes to maintain motivation. (2) For Parents: Use playdough at home as a constructive alternative to reduce screen time while strengthening finger muscles. (3) For School Administrators: Standardize the provision of economical, safe playdough materials in all Group A classrooms, supported by cleanup Standard Operating Procedures (SOPs) to teach children responsibility and address classroom management concerns.

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