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Practical Research on Cultivating Musical Rhythm Sense in Preschool Children in an Intelligent Interaction Environment

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SUMMARY: *Regarding the issues of feedback delay, lack of personalization, and the difficulty to assess classroom processes in the fostering of preschool children's musical rhythm, this research has built an intelligent mutual interaction environment which is fit for daily kindergarten classrooms and thus carried out a 12-week quasi-experiment research. This research's participating objects are 86 top-class kindergarten children who come from two public kindergartens in City A, among them 44 are in the experiment group and 42 are in the comparison group. The experiment group got intelligent mutual rhythm classes three times each week for 20 minutes for each class, meanwhile the comparison group attended traditional music activities which had same topics and same time length. This research has assessed testees in five aspects: rhythm feeling, rhythm copying, beat synchronization mistake, speed stability, and class participation, and has examined process changes by using class records. Results thus discovered that the experiment group's total rhythm mark elevated from 61.84 to 79.36, which is obviously higher than the comparison group's mark that is 69.08. The experiment group has shown bigger enhancements in rhythm perception exactness, rhythm imitation exactness, synchronization mistake, and tempo stability. On the task aspect, the biggest promotion were discovered in path striking, elementary striking, and rhythm imitation; Attendance proportions had significant positive correlation with these increases. Factor analysis indicated that visual cues and the highlighting of motor errors played a critical role in improving accuracy and reducing error correction time. This research proves that intelligent mutual action surroundings can effectively promote preschool kids' music rhythm feeling, and give out practical roads for assessing music activities and directing teachers to make changes in kindergarten places.*

KEYWORDS: *preschool children; smart interactive environment; musical sense of rhythm; embodied learning; quasi-experimental study*

1 Introduction

In the environments for children before primary school, music activities frequently adopt the forms of nursery rhyme body movements, hand-clapping imitations, and collective games; however, rhythm teaching usually still is restricted to whole-class following and oral rectification: teachers have difficulty in at the same time finding individual differences among children about starting the beat, keeping the beat, and changing to match new speeds, hence feedback frequently comes after the movement has finished, therefore classroom participation depends more on repeated reminding instead of on visual assistance. Current duration-wise research shows that early-time joint music activities in home environment have continuous

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connection with children's later attention adjustment, social-friendly behaviors, and digital concept formation; Quasi-experiment researches in kindergarten places also prove that long-time music-movement exercises can promote rhythm identification, rhythm copying, and motion coordination; The newest systematic summaries and combined analyses further point out that music practice has a stable positive influence on inhibition control, working memory, and cognitive flexibility among children from 3 to 6 years old, and that rhythm practice is also clearly connected with early reading ability development [1-4].

Theoretical explainings of children's rhythmic growth are also changing from skill-based depictings toward body-embedded and environment-related viewpoints. Related studies indicate that the feeling of rhythm is not a single hearing judging capability, but rather a child's ability that can form time connections between hearing signals, body actions, and environment restrictions [5]. Under this frame, body synchronous movement, beat repeating, music-movement assignments, and group cooperation activities are more and more utilized to explain how children form stable rhythm anticipations, which therefore influence their self-control and classroom conduct [6-9]. Although this kind of research gives a clear teaching frame for early childhood rhythm education, most researches still mainly depend on teacher observations or assessments of one single class, hence it is hard to continuously record the fine processes that are included in children's ability to get into the beat, correct the deviations, and keep the speed of music.

Along with digital tools being blended into early childhood education sites, the interactive methods of music education have been expanded from recorded performance and electronic toys to mobile app programs, networked music instruments, and AI-aided platforms. The early-period research which was carried out by de Vries has indicated that the technology holds application worth in the preschool music study; however, the expenses of apparatuses, the specialized capability of instructors, and the accommodation to surroundings still are key elements which have effect on the implementation [10]. Follow-up research has further proven that digital musical instrument application programs for little children can promote accessibility and engagement degree, while IoMusT and AI platforms are able to realize real-time beat cues, motion capture, and personalized feedback [11-14]. However, current researches have main put emphasis on tool usable degree, whole participation degree, or platform construct work, and analysis about "how intelligent interaction surroundings particularly affect the growing process of music rhythm feeling among preschool kids" still has not enough.

From the angle of putting into practice, a lasting difficult problem in preschool music education is that teachers do not have enough preparation. Large-scale investigations and interview researches show that kindergarten teachers on the whole do not have enough curriculum experience, self-confidence and transferable methods in music and movement teaching, therefore there has for a long time existed the requirement for specialized training [15, 16]. The analysis of documents about curriculum practice and quality evaluation also shows that although music activities are often considered to be "already arranged", the feedback about the quality of children's music study, the diversity of activities, and the feasible ways for promotion is still not enough [17, 18]. Therefore, teacher education research has already found that weak musical reading ability and inadequate practice support are problems that need direct solution in the early childhood education domain [19]. This shows that only increasing technical apparatus cannot automatically get converted into higher-quality rhythmic education; classroom task frame structures, feedback mechanisms, and teacher diagnosis interactive links must be designed in the collective.

Researches in the gone two years upon multisensory music systems, technology-pushed movement, and mixed-reality rhythm activities have proven that interactive technology is able to change children's movement modes, synchronous experiences, and social collaboration.

However, empirical research directly addressing the intersection of "regular kindergarten classrooms-rhythmic sense-smart interactive environments" remains limited, particularly lacking practical studies that simultaneously integrate perceptual testing, movement synchronization data, classroom participation records, and deployment feasibility. Based on this, this study targets children in senior kindergarten classes at two public kindergartens in a certain city. We constructed an intelligent interactive rhythm training environment focused on beat perception, rhythm imitation, and tempo maintenance, and conducted research around three key questions: Firstly, is it possible that this environment can obviously promote the core targets of the musical rhythm perception of little children? Second, thus, do there exist distinctions in improvement routes among different task categories and degrees of participation? Third, what are the individual functions of real-time feedback components, origins of classroom mistakes, and the relevant influences for kindergarten practice? This research puts emphasis on three important domains: working out an intelligent mutual rhythm training plan that is fit for everyday classroom utilization; to establish a multi-source evaluating frame which integrates perception, movement, and process record logs; and thus providing experience-based proof for the cooperation-based design of "environment-task-feedback-teacher" in the preschool music rhythm teaching activity.

2 Methods

2.1 Research Participants, Intelligent Interactive Environment, and Data Collection

For the guarantee that the follow-up effect assessments can be built upon comparable samples, this research at first carries out the definition of the study objects, field settings and data origins. This research has used a quasi-experimental plan in kindergartens, which was carried out in four senior kindergarten classes at two public kindergartens of City A, and has enrolled total 86 children whose age are 5 to 6. The experiment group included 44 children, and the comparison group included 42. The standards we use to include participants contain: hearing which is normal, and basic functions of movement; capacity of finishing group imitation work and oral order assignments; and in the past six months, there is no systematic training on instrumental music. Conditions that lead to exclusion are: continuous absences that pass 20% of all class teaching hours; the circumstance that core tasks in the pre-test have not been finished; or the simultaneous lacking of both video data and log data. All children have been given hidden numbers in the information system; fathers and mothers have put their signatures on the informed consent documents; and the kindergartens have reached agreement that classroom videos and platform records would be only utilized for the analysis of research.

The smart interactive environment was set up in the kindergarten's existing music activity room. The hardware things included a short-distance projection instrument, a depth capturing camera, a rhythm stepping mat, surrounding sound speakers, an LED beat light band, a teacher's flat panel control module, and a local data node. The projection module has shown beat routes, rhythm pieces, and group cooperation areas; the depth camera has collected the step moving, hand clapping, arm swinging and stop motions of children; the beat pads carry out recording of time stamps for hand and foot starting signals; the sound equipment and glowing bars synchronously give out audio pulses and vision prompts; the tablet that the teacher holds is utilized to set speed, difficulty, and feedback threshold values, and it shows in real time the beats that were missed, the beats that came early, the pauses that were prolonged, and the quantity of repeated corrections. For the purpose of reducing the entrance threshold that kindergartens face when using this system, the system is run on a local area network (LAN), which makes the recording and playing back of classroom data able to be finished without depending on the internet.

Our data origins have four big classifications: children's basic situation materials and attendance registration forms, pre-test and post-test task score results, classroom process record documents, and teacher observation records and video encoding works. At the log level, each cue event retains the standard beat time, the child's response time, response type, number of corrections, and duration of valid participation.During preprocessing, single-task records with fewer than six valid time points were excluded; outliers with intervals between adjacent responses of less than 100 ms or greater than 2,000 ms were marked as invalid responses; when the missing data rate in a single lesson log exceeded 30%, that lesson was used only for process description and was not included in the main effects analysis. The sample composition and pre-test homogeneity results are shown in Table 1.

Table 1: Sample Composition and Pre-test Homogeneity Test

Metric	Experimental Group (n=44)	Control Group (n=42)	t/χ^2	*p*
Male/Female	23/21	22/20	0.00	0.983
Age (Months)	67.8±3.4	68.1±3.1	-0.43	0.671
Weekly Family Music Interaction Frequency (times)	3.2±1.1	3.0±1.0	0.86	0.392
Pre-test Comprehensive Rhythm Score	61.84±8.73	62.11±8.51	-0.15	0.879
Pre-test Rhythm Perception Accuracy (%)	64.70±10.20	65.10±9.80	-0.18	0.857
Pre-test Synchronization Error (ms)	184.60±34.80	182.90±35.50	0.22	0.825

Note: The comprehensive rhythm score is a standardized composite indicator; none of the between-group differences reached statistical significance.

To illustrate how the classroom environment integrates cue output, motion capture, real-time correction, and subsequent evaluation into a single data loop, the composition of the intelligent interactive field is shown in Figure 1.

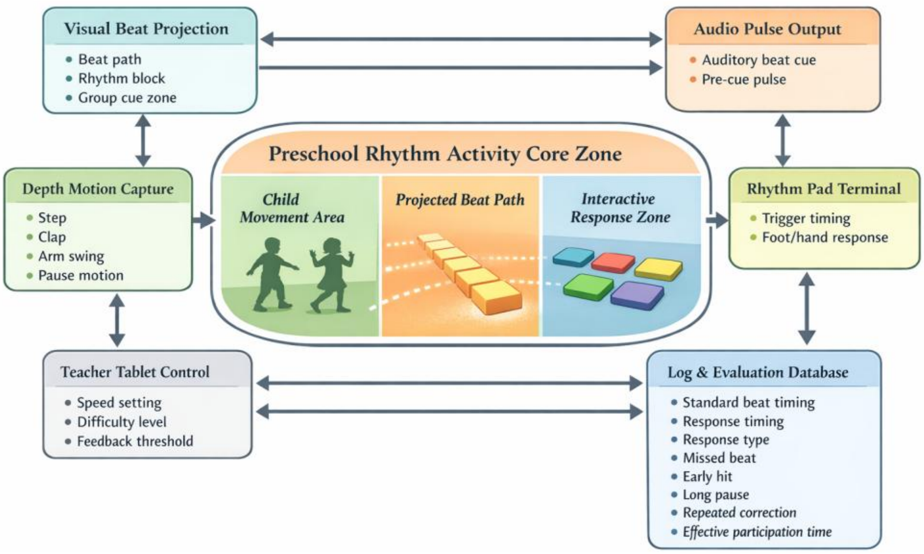

Figure 1: Composition and Data Loop Diagram of the Intelligent Interactive Rhythm Training Environment.

In Figure 1, the visual projection things and audio impulse things together act as the rhythm prompt signals. After children complete rhythm reactions including step moving, hand clapping, arm swinging inside the core activity area, movement data and trigger time stamps are got together in same time by movement sensors and beat following equipment. The system at this moment then recognizes skipped heart beats, ahead-of-time beats, overlong pauses, and repeated mistakes, hence saves the related data into the log and the assessment database. The teacher's control interface is not a direct replacement for in-class activities; instead, after it has perceived the classroom situation, it carries out fine adjustment on the speed, difficulty and feedback threshold, hence it feeds the adjusted outcomes back into the prompts for the next round of tasks. By this method, classroom training, procedure recording, and following assessment all make use of the identical data origin. Therefore, the spatial structure that is depicted in this section has methodological meaning, hence it is not only a showing of instruments.

2.2 Rhythm Cultivation Program and Indicator Development

After the sample and the research environment were got ready, the core question thus changed to how "rhythm training" could be arranged into classroom assignments which were able to be operated, recorded and evaluated. The experiment accepting group received a 12-week intelligent mutual rhythm course, gathering three times each week with 20 minutes for each class, the total is 36 classes. Every activity segment contained a 3-minute warm-up movement for setting the beat, a 12-minute core rhythm work, a 3-minute partner cooperation work, and a 2-minute check and relaxation stage. This curriculum was divided into four progressive stages on the basis of difficulty: The first to second weeks placed stress on constructing stable beat perception and beat-entry responses; Weeks 3 through 5 let the training of rhythm imitation and short-phrase repeating get enhanced; In the sixth through eighth weeks, we imparted the knowledge concerning tempo alterations, the handling of pauses, and the sustaining of tempo; The 9th until 12th weeks have contained the work of path-based tapping, activities of group coordinate, and works of transferable creative composition. The comparison group utilized the identical theme, the identical quantity of courses, and alike study goals, but utilized teacher-centered oral explanations, hand-clapping, and traditional teaching tools for arrangement, without giving real-time visual hints or system-level motion feedback.

For translating classroom behaviors into stable measurement indexes, this research defines rhythmic feeling as the comprehensive manifestation of "beat perception, rhythm reproduction, synchronization accuracy, and tempo stability." About the perception dimension, a task which contains 20 items of beat/rhythm recognition was utilized to produce P_i; As for the reproduction dimension, we employed a five-phrase rhythm imitation task to produce M_i; We have carried out the calculation of synchronization accuracy and tempo stability on the basis of platform logs. The curriculum units, interactive help, and data measurement indexes are presented in Table 2.

Table 2: Intervention Modules, Intelligent Feedback, and Data Acquisition Specifications

Module	Classroom Task	Intelligent Interaction Support	Collected Variables	Evaluation Purpose
Steady Beat Follow	Step to the beat, clap to the beat, on-beat entry	Beat light strip + projected beat path + audio prompts	Entry timing difference, missed beats, effective participation duration	Synchronization accuracy, classroom engagement
Rhythm Imitation	Reproduce 2-4 beat phrases, pause reproduction	Rhythm block segmented display + playback prompts	Number of correct reproductions, error correction counts	Rhythm reproduction ability
Speed Maintenance	Speed variations, sustained steady speed, pause recovery	Pre-prompt color changes + beat density adjustments	Coefficient of variation in intervals, direction of deviation	Speed stability
Path Tapping	Path movement, body percussion coordination	Path projection + area trigger feedback	Area hit rate, capture rate	Action-rhythm mapping
Group Coordination	Partner clapping, group rotation, synchronized ending	Synchronization area display + teacher monitoring for group	Collaboration completion rate, waiting duration	Social rhythm coordination

Definitions of core computational metrics, as shown in Equations (1) to (3).

$$E_i = \frac{1}{N_i}\sum_{n=1}^{N_i}\left|t_{i,n}^{(r)} - t_n^{(b)}\right| \tag{1}$$

In the equations, $t_n^{(b)}$ denotes the time of the n standard clap point, $t_{i,n}^{(r)}$ denotes the response time of the i child at the n valid clap point, and N_i represents the number of valid clap points for that child.

$$S_i = \frac{\sigma(\Delta t_{i,n})}{\mu(\Delta t_{i,n})} \tag{2}$$

In the formula, $\Delta t_{i,n}$ represents the interval between adjacent responses.

$$R_i = 0.30\hat{P}_i + 0.30\widehat{M}_i + 0.20(1-\hat{E}_i) + 0.20(1-\hat{S}_i) \tag{3}$$

In the formula, P_i represents the rhythm perception score, M_i represents the rhythm imitation score, and $\hat{P}_i$, $\widehat{M}_i$, $\hat{E}_i$, and $\hat{S}_i$ are metric values normalized to [0,1]. Since E_i and

S_i are better when lower, the composite score uses 1-$\hat{E}_i$ and 1-$\hat{S}_i$ in the calculation. Finally, R_i is linearly mapped to a 0-100 score for comprehensive comparison.

The superiorities of this design are mainly manifested in three aspects. First of all, the beat prompting things have been expanded from a single words instruction to a combination that has auditory, visual, and kinesthetic feedback, hence it reduces the reliance of children on repeated teacher showings in the phase of beat entry. Second, the feedback has been changed from the post-task evaluation to the time when the action is happening, thus permitting children to perceive and right away correct early beats, missed beats, and lengthened pauses inside the same task. Third, teachers no longer view only the class as a whole but can use the control interface to quickly identify children with high error rates and tasks with high failure rates, thereby enabling fine-tuning rather than a complete interruption. The relationship between the multimodal rhythm task and real-time feedback is shown in Figure 2.

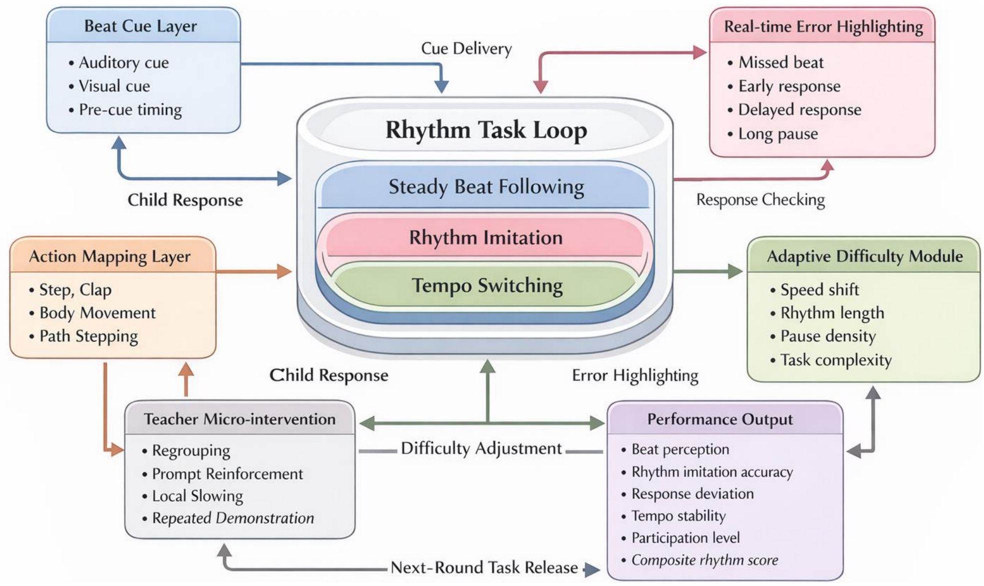

Figure 2: Multimodal Rhythm Task and Real-Time Feedback.

In Figure 2, the beat cue layer at first gives auditory and visual rhythm cues. In the circle of task work, children complete actions of following beats, imitating movements and adjusting speed. After that, the system according to motor performance finds out problems like missing beats, early beats, late entry, long pauses, and gives instant feedback for the present task. The difficulty adjusting module does not work alone from the classroom but dynamically renews speed, rhythm time length, and task complexity according to current performance; Teacher micro-interventions mainly are used for the partial reinforcement and rhythm re-adjustment. After this circulation, perception, imitation, deviations, stability, involvement are consolidated into a performance result, which supports the afterward evaluation and the planning of the next task circle.

2.3 Experimental Design and Evaluation Protocol

From the perspective of research method, this research has used a kind of quasi-experiment design which includes pre-test, intervention and post-test stages, and an extra process monitoring spot has been added in the sixth week in order to track the changes of learning speed. Both the pre-test and post-test, which were arranged one week before the intervention and one week after the intervention respectively, were conducted by the same group of research assistants in different classrooms. Core targets include rhythm perception correctness, rhythm copying correctness, beat alignment error, speed stability, and comprehensive rhythm score. Assistant measures include classroom participation, task finishing rate, mistake modification time length, and ratio of valid participation time. Classroom degree of participation in class is evaluated by utilization of a 5-point scoring system, two independent coders carry out scoring on video recorded materials; When the difference between obtained scores surpasses 1 point, therefore a third coding worker carries out a review work.

For the control of teacher influences, both the experiment group and the contrast group adopted the identical topic-based course arrangement and unified task target statement descriptions. The teachers who carried out experiment finished 6 hours of training and two test practice sessions before the formal intervention; The content of training includes the standardization of task commands, the startup flow of equipment, the processing of abnormal conditions, and the rules of observation and record. One 10-item implementation consistency check list was utilized in the research process for recording task order, instruction employment, speed settings and feedback time arrangement. With regard to statistical analysis work, baseline difference conditions were evaluated by utilizing independent-sample t-tests and chi-square tests; The main influence of pre-tests and post-tests we have analyzed by ANCOVA, which takes pre-test scores as the covariant; The process moving tracks in the experiment group have been analyzed by the method of repeated measure analysis; the connection between attending class and achievement increases was evaluated by making use of Pearson correlation; and the comparisons of factor decomposition among four feedback conditions were carried out by means of repeated measures ANOVA. The level of significance has been set as 0.05.

In order to guarantee that the explanation of outcomes includes the result, procedure and execution levels at the same time, this research has cut the evaluation scheme into three levels: the first level is the result level, which deals with whether the intelligent mutual acting environment promotes young children's core rhythm expression; the second layer is the task layer, it inspects differences on the acquisition among various kinds of rhythmic tasks; and the third layer is the execution level, which recognizes feedback parts, error origins, and possibility for putting into practice in kindergartens. The overall experimental protocol and evaluation pathway are shown in Figure 3.

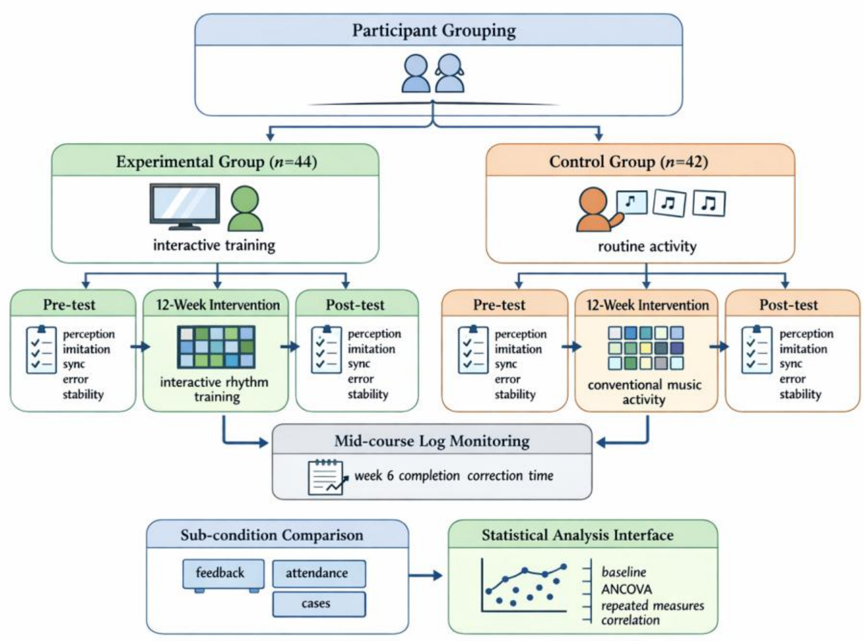

Figure 3: Quasi-experimental protocol and evaluation pathway diagram.

In Figure 3, by first entering two parallel roads-the experiment group and the comparison group-participants finish a unified pre-test before the interference. Afterwards, the two groups separately get either the clever interactive rhythm course or traditional music activities, respectively. In the sixth week, process recording materials are gathered at the same time from two groups to write down middle-term performance indicators such as task finishing rates, mistake correction time length, and time length of active taking part. When the 12-week intervention was finished, two groups all finished a post-test that was same as the pre-test, and thus further went to sub-conditions for comparing feedback conditions, participation levels, and representative case studies. At last, the outcomes got from the pre-test, process watching, and post-test were put together into a statistical analysis interface, therefore permitting baseline comparisons, main effect examinations, and correlation analyses to be finished inside the same protocol path.

3 Results and Discussion

3.1 Main Effects: Rhythm Perception, Rhythm Imitation, and Synchronization Performance

After the 12-week intervention, this part first discusses whether the intelligent interactive environment on the whole brought enhancement to the musical rhythm perception of preschool children. The outcomes of the main effect items are exhibited in Table 3. The composite rhythm score of the experimental group was raised from 61.84 ± 8.73 to 79.36 ± 7.12, which represents 17.52 points of increase; The control group's score had a rise from 62.11 ± 8.51 to 69.08 ± 7.95, which represents an increment of 6.97 points. When we carry out analysis by taking post-test as dependent variable and pre-test as covariate, the difference between groups has significance ($F = 29.47$, $p < 0.001$), and partial effect size is 0.26. From the aspect of sub-indicators, the experimental group showed bigger enhancements in rhythm perception correctness, rhythm imitation correctness, beat synchronization mistake, and speed stability, therefore the most obvious differences between groups were seen in rhythm imitation correctness and beat synchronization mistake.

Table 3: Comparison of Key Indicators Before and After the Intervention

Metric	Experimental Group Pre-Test	Experimental Group Post-Test	Control Group Pre-Test	Control Group Post-Test	*F*	*p*	Biased effect quantity
Comprehensive Rhythm Score	61.84±8.73	79.36±7.12	62.11±8.51	69.08±7.95	29.47	<0.001	0.26
Rhythm Perception Accuracy (%)	64.70±10.20	81.90±8.40	65.10±9.80	72.40±8.90	21.63	<0.001	0.21
Rhythm Imitation Accuracy (%)	60.90±11.40	79.80±9.10	61.30±10.90	68.70±9.60	27.41	<0.001	0.24
Beat Synchronization Error (ms)	184.60±34.80	118.70±27.30	182.90±35.50	156.20±31.10	19.08	<0.001	0.19
Speed Stability CV (%)	18.90±4.60	11.70±3.80	19.10±4.20	16.50±4.10	16.44	<0.001	0.17
Classroom Engagement (1-5)	3.12±0.41	4.28±0.36	3.09±0.39	3.62±0.43	34.12	<0.001	0.29

Note: *F* represents the ANCOVA results with previous measurements as covariates.

From the trajectory analysis, the growth slopes of the two groups had not yet fully diverged during the first 4 weeks, but the difference expanded rapidly after Week 8. The trajectories of the composite rhythm scores for the two groups at the four time points are shown in Figure 4.

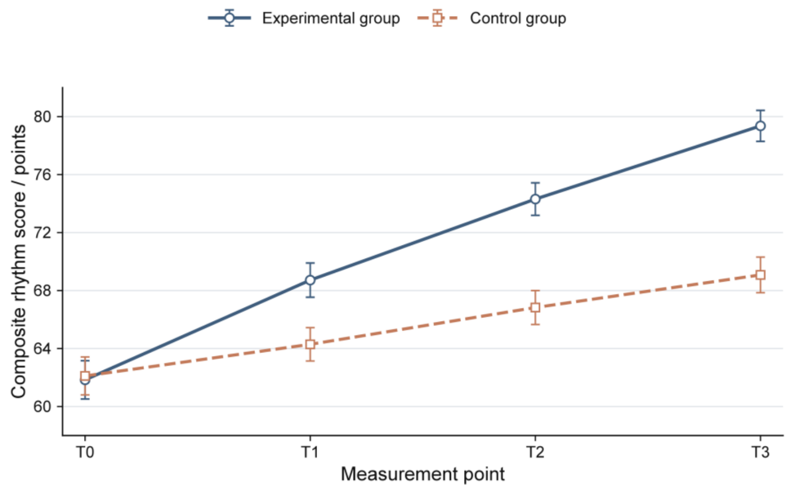

Figure 4: Trajectory plots of the composite rhythm scores for the two groups at four time points.

In Figure 4, the experimental group's composite rhythm score increased from 61.84 to 79.36, while the control group's score increased from 62.11 to 69.08. The two groups basically overlapped at T0, started to separate at T1, and the distance became even larger after T2, hence it shows that the helpful effect of the smart interaction environment is not focused on one single classroom stimulation but is slowly accumulated through the continuous process of building rhythm expectations and revising mistakes. With regard to the promotion of final scores, the experiment group has an increment of 17.52 points when compared with the pre-test, hence the comparison group has an increment of 6.97 points; the dissimilarity in growth speeds between the groupings is in accordance with the outcomes of the covariance analysis inside Table 3. The alterations of synchronization error can further give explanation to the origin of the promotion in the composite score. The alterations of beat synchronization error on the four time points are displayed by Figure 5.

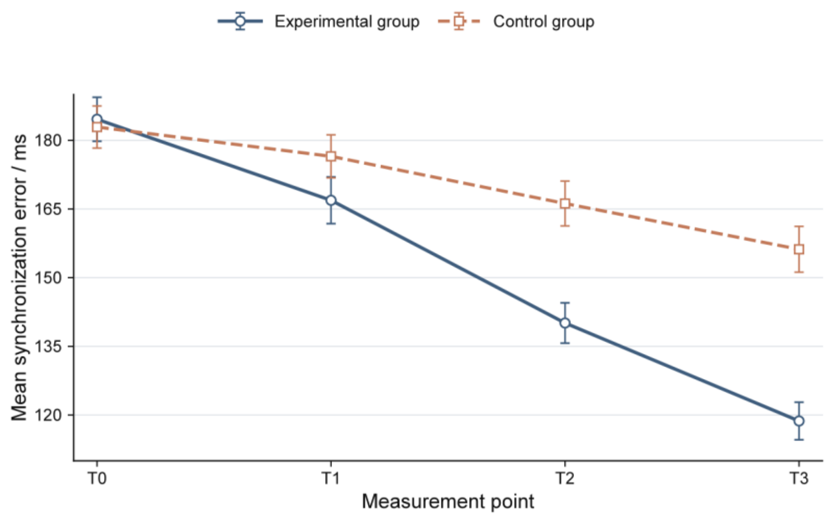

Figure 5: Changes in beat synchronization error across four time points for the two groups.

In Figure 5, the average synchronization error of the experimental group it decreases from 184.6 ms to 118.7 ms, therefore the error of the control group decreases from 182.9 ms to 156.2 ms. After the time point T1, the descending speed in the experiment group was obviously larger than that in the comparison group; by Time 3, the gap between the two groups had attained 37.5 ms, hence indicating that vision advance hints and instant correction more quickly cut down the time departure between the children's movement responses and the normal rhythm. This result is got support by the continuous becoming larger gap in the comprehensive rhythm marks, hence it shows that the progress of the experiment group was mainly showed on time accuracy.

3.2 Task-Specific Differences and Process Changes

After confirming the overall effect, it is necessary to further determine in which tasks the improvement primarily occurred and whether this improvement depends on the children's sustained participation. The task-level gain matrix is shown in Figure 6.

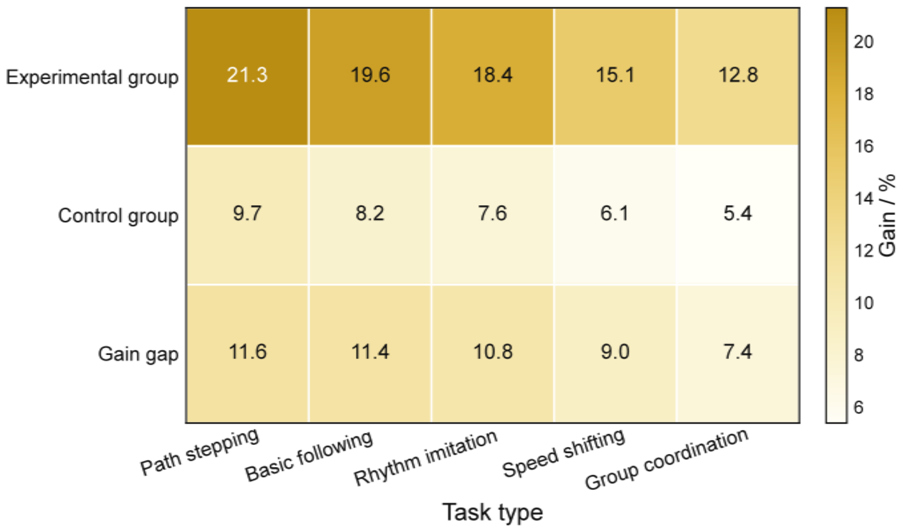

Figure 6: Heatmap of gains across different rhythmic tasks.

In Figure 6, the experiment group has displayed the biggest promotion on three task kinds of path knock, basic knock and rhythm imitation, reaching 21.3, 19.6, 18.4 percentage points, respectively; the corresponding obtainments for the control group were 9.7, 8.2, and 7.6 percentage points. The performance of the experimental group on tempo-shifting tasks and group coordination tasks also obtained significant improvement, although the degree is relatively smaller, being 15.1 and 12.8 percentage points respectively. The most obvious differences were discovered in tasks that demand children to process at the same time spatial paths, movement rhythms, and beat signals, hence it suggests that the intelligent interactive environment provides bigger advantages for rhythm tasks that have higher "perception-action mapping" requirements.

This outcome does not mean that higher-order assignments are not fit for preschool kids, but it puts forward that the speed of development on rhythmic capability changes in different tasks. Basic beat hitting and rhythm copying display fast promotion because their time arrangements are distinct and their mistake fixing targets are single; Speed changes need children to re-set their inner time reference in a brief time period, while group cooperation is furthermore affected by companion waiting, changing rhythms and common attention, hence slower progress is got. Classroom recording materials show that the group which did experiment had an average of 4.7 different mistake-correcting happenings each class in the first two weeks, hence this number dropped to 1.9 by the eleventh and twelfth weeks; the proportion of valid participation time has the increase from 71.4% to 86.8%. These data of process show that children do not only repeat actions, but through many task cycles, gradually change outside hints into inside control of rhythm.

The extent of participation has further influenced the size of the obtained benefits. Therefore, the children who are in the experimental group have a remarkable positive interrelation between their attendance rate and their total rhythm improvement, with $r = 0.62$, $p < 0.001$. To speak concretely, children whose attendance rate is higher than 90% have obtained an average increase of 19.8 points, those who are in the 80%-90% scope have obtained an average increase of 16.4 points, and those who are below 80% have obtained an average increase of 11.2 points. At the same time, when we group children according to pretest performance, children who are in the bottom one-third of pretest scores have an average score increase of 20.4 points, this increase is higher than 17.1 points of the middle group, and also higher than 13.6 points of the high-performing group.

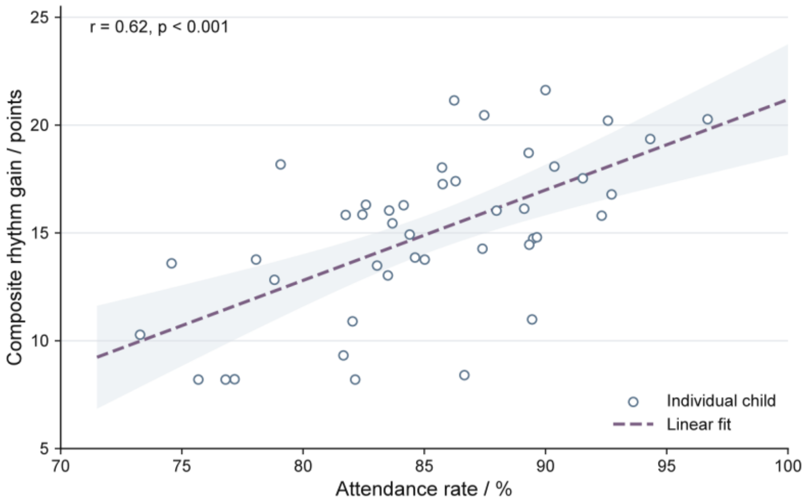

Figure 7: The relationship chart between attendance rate and comprehensive rhythm gain.

In Figure 7, the scatter diagram displays a whole positive distribution, which shows that the intelligent mutual environment has a more obvious compensation effect on children who have weaker basic abilities. This reason lies in that children who have weaker basic knowledge are more easily covered by the speed of the whole class in traditional teaching rooms, while systematical remindings and instant rectifications give them more clear reference scopes. Therefore, the intelligent mutual-action environment does not gather classroom merits on those children who already have good performance; on the contrary, it enlarges the space for children who have lower beginning positions to make up the gap to a certain degree.

3.3 Factor Decomposition, Sources of Error, and Implications for Implementation

After we have confirmed the main effects and the differences between tasks, the final step is that we identify the key factors which drive the improvement, and we determine whether this approach can be carried out continuously in the environments of preschools. For this purpose, this research has chosen 24 children from the experiment group in the 9th to 10th weeks, and has used a within-subjects repeated measure design, for the comparison of four feedback situations: complete feedback, taking away visual pre-prompts, taking away motion error marking, and keeping only the teacher's verbal prompts.

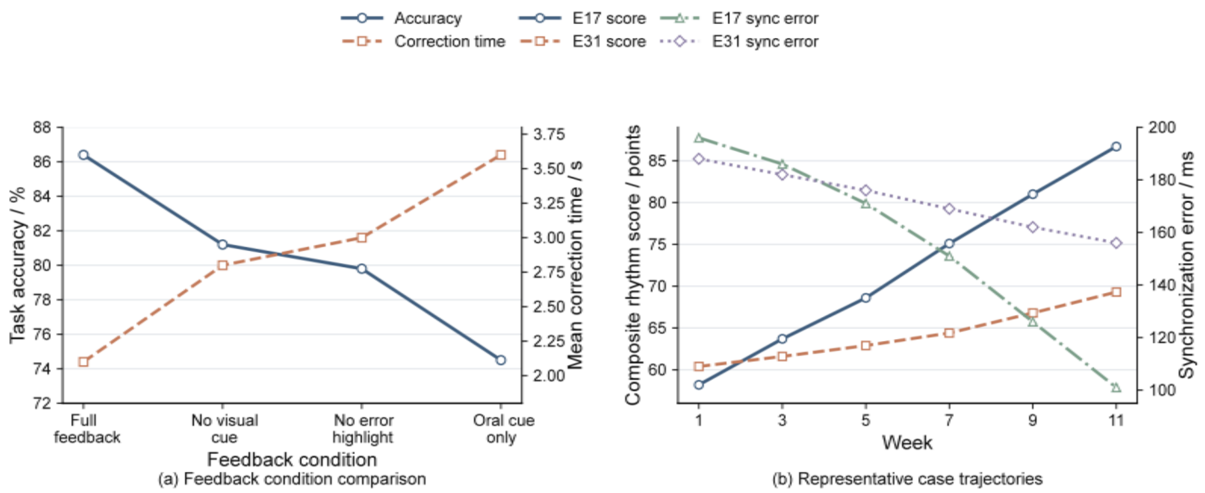

Figure 8: Comparison of Feedback Elements and Representative Case Trajectory Chart.

Task accuracy and average correction duration under different feedback conditions are shown in Figure 8(a). In Figure 8(a), task accuracy under full feedback was 86.4%; it decreased to 81.2% after removing visual cues, to 79.8% after removing motion error highlighting, and further to 74.5% when only verbal teacher prompts were retained;The corresponding average correction durations were 2.1 s, 2.8 s, 3.0 s, and 3.6 s, respectively. A relatively stable gradient difference emerged among the four conditions, indicating that visual pre-cues and motion error highlighting are not redundant but rather act on two key stages: entry into the beat and continuous correction.Visual pre-cues more directly influence children's anticipation of the beat arrival timing, while motion error highlighting primarily facilitates deviation recovery during sustained rhythmic maintenance; when both are present, children find it easier to catch the beat and maintain temporal stability in subsequent movements, resulting in the highest accuracy and shortest correction duration under the full feedback condition.

With regard to the efficiency of deployment, the average time which is needed to make the system start working in the classroom was 8.6 minutes in the first three class sessions, and it becomes stable at 4.1 minutes after the fourth week; In each single class lesson, the effective obtaining rate of logs has attained 93.7%; After each teaching class, teachers on average use 6.8 minutes to carry out the review work of class reports. Different from the main effect outcomes, this shows that the advantages of this environment are not obtained by paying the price of too much organization cost, but are instead completed inside an allowable preschool time frame. What is more important, teachers have not been replaced, but have completed the transformation from "full-flow demonstrators" to "rhythm diagnosers and fine adjusters." This change is consistent with conclusions gotten from studies about digital tool combination and teacher growth, which point out that only technology cannot by itself produce high-quality music education; The thing that really possesses meaning is the synthetic effect which lies among task arrangement, feedback principle, and teacher's assistance. In addition, this research's high-frequency, short-time intervention-that is three 20-minute meeting every week-accord with the already confirmed best dose ranges for early stage childhood music study.

The origins of mistakes were mainly gathered together in three kinds of situations. First of all, in group cooperation work, children who obstruct each other's sight lowered the quality of movement capture, hence making the system wrongly explain individual reactions as delays. Second, some children at the beginning too much depended on the visual light strip, showing a surface-level "move only when seen" dependence, which made their progress in tempo change tasks slower than that in basic beat-following work. Third, classroom noise and slight inconsistencies in the teacher's rhythmic cues amplify temporal fluctuations in the pause-resumption task. To illustrate these differences, the developmental trajectories of representative cases over 12 weeks are shown in Figure 8(b). Figure 8(b) compares the continuous developmental processes of high-gain case E17 and low-gain case E31. E17's composite rhythm score increased from 58.2 to 86.7, and the synchronization error decreased from 196 ms to 101 ms; E31's score increased from 60.4 to 69.3, and the synchronization error decreased from 188 ms to 156 ms. The two kids began at alike levels in the pre-test stage, but their developing roads went apart greatly after that time: E17 got into a long-lasting bettering stage after Week 4, with marks going up stably and synchronization mistake getting smaller quickly; The progress of E31 was comparatively slow, with many late inputs when speed changes and recovery after stops, thus restricting the degree of promotion in the later phases. Further checking of documents discovered that E31 had an accumulative sum of 6 absences and often showed late inputs in the speed change experiments. The individual differences which are displayed in Figure 8(b) show that although the intelligent interactive environment can raise the average level of classroom performance, certain children still have the need for more steady attendance and more concentrated individual support. Near-term researches on multi-sense music systems, technology-pushed movement, and mixed-reality rhythm activities in the same way prove that interactive technologies can greatly change children's motion organization and synchrony experiences, but their effect degree is highly depended on feedback design and context adaptation [20-22].

4 Conclusion

This thesis places stress on classroom approaches for cultivating musical rhythm cognition in preschool children within an intelligent interactive environment. It has constructed a research work flow which contains space arrangement, mission arrangement, course record, and outcome evaluation, and hence has verified its practical value through a 12-week quasi-experimental study. The research conclusions that we obtain can be summarized into three points.

(1) This research has finished a closed-loop plan for subject arrangement and data gathering in preschool music activities. Through putting together cue output, motion capture, log keeping, and teacher adjustment in the identical classroom environment, this research therefore enabled the lasting recording and analysis of rhythm feeling, rhythm copying, synchronization error, and participation behavior under a single framework.

(2) The intelligent interaction type intervening measures have the stable positive influence upon the rhythm ability of children who are at preschool age. The composite rhythm score of the experimental group has the increase from 61.84 to 79.36, hence it exceeds the 69.08 score which the control group has; Meaningful promotion has been seen in rhythm perception exactness, rhythm imitation exactness, synchronization mistake, and speed stability. Further contrastive analyses hence showed that visual promptings and motion error emphasizing respectively aimed at beat-entry and continuous rectification, with the finest outcomes hence obtained when both of these two were combined.

(3) This intervening measure shows possibility of being done in kindergarten places, though its putting into practice is still influenced by factors like consistent attendance, group overlapping, and noise inside classrooms. In the future, research work ought to enlarge the sample quantity and further make better low-occlusion data gathering, adaptive task adjustment, and individual support mechanisms, hence to promote the outer validity and actual application property of these research results.

About the Author

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