Research on the Impact of Urban Park Design with Natural Elements Based on Behavioral Experiments on Children's Cognitive Development

Abstract

Against the backdrop of the rapid development of urbanization, children's opportunities to get in touch with nature are decreasing day by day, and the importance of urban parks with natural elements for children's cognitive development has become increasingly prominent. However, the current design of urban parks has deficiencies in meeting the cognitive needs of children. This study focuses on the relationship between urban parks with natural elements and children's cognitive development. By using scientific methods such as behavioral experiments and dividing children into experimental groups and control groups, it thoroughly explores the impact mechanism of urban parks with natural elements on children's cognitive development in multiple dimensions such as attention, memory, and problem-solving abilities. The research results show that urban parks with natural elements have a positive promoting effect on children's cognitive development, which is specifically reflected in significantly improving children's attention concentration, enhancing memory performance, and improving problem-solving abilities. Based on this, this study provides a scientific reference framework for the design of child-friendly urban parks, which helps to optimize the configuration of natural elements in urban parks so as to better meet the needs of children's cognitive development and promote children's all-round growth.

Keywords: Natural elements, Urban parks, Children's cognition, Behavioral experiments

1. Introduction

With the accelerated development of urbanization, children's opportunities to access nature have decreased significantly, which has had a profound impact on their cognitive development [1]. Urban parks with natural elements, as an important type of public space, not only play a crucial role in improving the urban ecological environment but also serve as significant places for children to obtain natural experiences and enhance their cognitive abilities. However, the existing designs of urban parks have failed to fully consider children's cognitive needs and the characteristics of their diverse development. Therefore, there is an urgent need to provide theoretical support for their optimized design through scientific research.

A. Research Background and Significance of Children's Cognitive Development

This study aims to explore the specific impacts of urban parks with natural elements on children's cognitive development through rigorous behavioral experiment methods. The research focuses on the independent and interactive effects of different natural elements (such as plants, water bodies, terrains, etc.), systematically evaluates their promoting effects on cognitive dimensions such as attention, memory, and problem-solving abilities, and provides an innovative reference framework for the design of child-friendly urban parks. This study integrates multidisciplinary theories such as environmental psychology, urban planning, and child developmental psychology, and systematically reveals the profound impacts of urban parks with natural elements on children's cognitive development. The research results not only provide a scientific basis for the optimized design of child-friendly urban parks but also offer specific guidance for policymakers and urban planners in improving children's growth environment. Through an interdisciplinary perspective and rigorous experimental methods, this study opens up new directions for future research on children's cognitive development and urban park design [7].

B. Research Methods and Innovation Points

To verify the role of natural elements in children's cognitive development, this study adopts a randomized controlled experiment design. Children in the experimental group participate in activities in the urban park environment with multiple natural elements, while children in

the control group carry out activities in the conventional park environment. Through multi-dimensional cognitive test tools (such as attention assessment, memory tasks, etc.) and high-resolution data analysis, the effects of natural elements on the improvement of children's cognitive abilities are quantified. In addition, the study introduces the variable of socioeconomic status (SES) to explore its moderating role in children's access to nature and cognitive gains.

1) Multi-dimensional Analysis of Natural Elements: For the first time, this study systematically evaluates the compound effects of combinations of natural elements (such as the interaction between plants and water bodies) on children's cognitive development, making up for the deficiencies in the research on single natural elements [2].

2) Rigorous Behavioral Experiment Design: Through the randomized controlled experiment, the difficulty in verifying causal relationships in observational studies is overcome, ensuring the scientificity and reliability of the research results [3].

3) Multi-level Cognitive Assessment: By using advanced cognitive test software and environmental data, the performance of children in dimensions such as attention and memory in different natural environments is comprehensively measured [4].

4) Exploration of Socioeconomic Variables: By introducing the analysis of the SES factor, the influence mechanism of socioeconomic conditions on children's access to nature and cognitive benefits is deeply revealed, providing data support for achieving environmental equity [5].

5) Mediating Role of Environmental Mechanisms: The indirect effects of natural elements in reducing air pollution, noise, and stress are explored, enriching the theoretical framework of how the natural environment promotes cognitive development [6].

2. Research Hotspots and Trends in Rural Ecological Landscape Biodiversity

C. Behavioral Experiment Design

This study adopts the design of a Randomized Controlled Trial (RCT), randomly dividing the participants into an experimental group and a control group. Children in the experimental group participate in activities in an experimental park that contains abundant natural

elements (such as plants, water bodies, terrains, etc.), while children in the control group conduct the same activities in a conventionally designed park. The experiment lasts for 12 months, and the specific impacts of natural elements are verified through regular evaluations of the cognitive abilities of the two groups of children [8]. Experimental scenario setting: Natural elements, such as dynamic water flows, areas covered by green plants, and diverse terrain designs, are added to the experimental park to create an environment with high exposure to nature.

D. Analysis of the Moderating Role of Socioeconomic Variables

The variable of socioeconomic status (SES) is introduced to explore its moderating role in children's access to the natural environment and the development of their cognitive abilities [11]. Data collection: The SES information of the participants' families is collected through questionnaires, including indicators such as parents' education levels and family incomes. Analysis methods: Hierarchical analysis and Hierarchical Linear Modeling (HLM) are adopted to explore the associations between SES and the improvement of children's cognitive abilities as well as the differences in the effects of natural elements.

E. Questionnaires and Interviews

To supplement the quantitative analysis, this study designs questionnaires and interviews for children and guardians to collect subjective experience data and reveal the motives and mechanisms behind behaviors [12]. Questionnaire content: It includes children's preferences for different natural elements and guardians' observations on the effects of children's activities. Interview content: It focuses on children's subjective feelings about park activities and their experiences with natural elements.

F. Multi-level Modeling Analysis

Through Hierarchical Linear Modeling (HLM) and Structural Equation Modeling (SEM), the direct and indirect impacts of natural elements, environmental improvements (such as air quality and noise reduction), and socioeconomic factors on cognitive development are analyzed [13]. Model construction: Modeling is carried out by combining the distribution of natural elements, cognitive test results, and socioeconomic variables. Mediation effect analysis: The mediating roles of air quality improvement and psychological stress reduction in the enhancement of cognitive abilities are explored.

G. Long-term Tracking and Longitudinal Study

To capture the long-term changes in children's cognitive development, this study designs a 12-month longitudinal study and regularly records the development trajectories of children's cognitive abilities [14]. Time series analysis: The potential benefits of long-term exposure to natural elements are analyzed through the dynamic changes in quarterly test data. Data comparison: The trends of changes in the cognitive abilities of the experimental group and the control group at different time points are compared to verify the long-term effects.

3. Research Hypotheses

The research hypotheses are based on the assumption that the urban park environment configured with natural elements can significantly enhance children's multi-dimensional cognitive abilities, including attention, memory, and problem-solving abilities. The specific research hypotheses are as follows:

H. Hypothesis on the Direct Impact of Natural Elements on Cognitive Abilities

It is hypothesized that in the park environment rich in natural elements, children's cognitive abilities (including attention, memory, and problem-solving abilities) will be significantly improved compared to those of children in the conventional park environment. Combinations of natural elements (such as plants, water bodies, terrains, etc.) will promote the development of children's cognitive abilities by directly stimulating their sensory stimuli and exploration behaviors.

I. Hypothesis on the Indirect Role of Environmental Improvements on Cognitive Abilities

It is hypothesized that natural elements have an indirect promoting effect on children's cognitive abilities by improving environmental quality (such as reducing the concentration of PM2.5 in air pollution and noise levels). We believe that lower levels of air pollution and noise may indirectly enhance children's cognitive performance by reducing their physiological stress, especially in the case of long-term exposure to the natural environment.

J. Hypothesis on the Moderating Role of Socioeconomic Status on the Effects of Natural Exposure

It is hypothesized that children's socioeconomic status (SES) will moderate the impact of natural exposure on their cognitive abilities. Children from high-SES families may obtain more significant cognitive benefits after being exposed to natural elements due to differences in resources and opportunities. However, we also assume that children from low-SES families can still significantly benefit from natural exposure after being in contact with the natural environment, and such benefits may, to some extent, make up for the negative impact of socioeconomic inequality on their cognitive development.

K. Hypothesis on the Cumulative Effect of Long-Term Natural Exposure

It is hypothesized that long-term exposure to natural elements can further strengthen their promoting effect on children's cognitive abilities. Over time, long-term and stable exposure to nature will gradually amplify the positive impact of natural elements on children's cognitive development. Especially after the children in the experimental group have experienced long-term exposure to the natural environment, the improvement of their cognitive abilities will show a cumulative effect, especially in the later stages of the experimental period (such as the T3 to T4 stage).

L. Hypothesis on the Impact of Behavioral Experiments and Data Collection

This study hypothesizes that through a rigorous randomized controlled experiment design and multi-level data collection (including cognitive tests, environmental monitoring, behavioral records, and questionnaires), the direct and indirect impacts of natural elements on children's cognitive abilities can be effectively revealed. We believe that through systematic data management and statistical analysis (such as multi-level modeling analysis), the mechanism of the role of the natural environment in cognitive development can be evaluated more accurately.

4. Experimental Design and Implementation

M. Experimental Objectives and Participants

Through rigorous behavioral experiments and quantitative analysis, this study aims to investigate the impact of urban parks with natural elements on children's cognitive development and explore the differentiated impacts of combinations of different natural elements

(plants, water bodies, terrains) on cognitive dimensions (attention, memory, problem–solving abilities) [19]. Fifty healthy children aged between 6 and 10 years were recruited and randomly divided into an experimental group and a control group, with 25 children in each group. Gender ratio: Males and females each accounted for 50%. The experiment was divided as follows: Experimental group: Experimental park (containing abundant natural elements). Control group: Control park (with conventional park facilities and a lack of natural elements). Socioeconomic status (SES): The children were evenly distributed among families with low, medium, and high SES to ensure the representativeness of the sample.

Table. 1.

Participant ID	Group	Age	Gender	SES	Attention Score_T1	Attention Score_T4	Memory Score_T1	Memory Score_T4	Problem–solving Score_T1	Problem–solving Score_T4
Experimental Group_1	Experimental Group	7	Male	low	76	86	66	91	72	88
Experimental Group_2	Experimental Group	6	Male	middle	62	88	67	92	74	88
Experimental Group_3	Experimental Group	7	Male	low	71	98	64	83	64	90
Experimental Group_4	Experimental Group	9	Male	middle	72	85	59	75	65	90
Experimental	Experimental	9	Male	high	68	82	73	82	64	88

Group_5	Group									
Experimental Group_6	Experimental Group	7	Male	high	63	94	60	91	65	87
Experimental Group_7	Experimental Group	6	Male	high	70	87	73	87	71	89
Experimental Group_8	Experimental Group	7	Male	high	79	80	74	91	71	99
Experimental Group_9	Experimental Group	6	Male	middle	65	84	65	78	72	95
Experimental Group_10	Experimental Group	8	Male	middle	77	89	59	84	71	86
Experimental Group_11	Experimental Group	10	Male	middle	79	80	59	83	76	93
Experimental Group_12	Experimental Group	8	Male	middle	62	96	59	86	77	98
Experimental Group_13	Experimental Group	10	Male	high	68	81	66	77	62	85
Experimental Group_14	Experimental Group	9	Male	low	67	90	63	79	73	96
Experim	Experi	8	Male	low	64	98	68	78	72	94

ental Group_15	mental Group									
Experimental Group_16	Experimental Group	6	Male	high	67	93	73	80	60	91
Experimental Group_17	Experimental Group	6	Male	low	60	94	56	88	67	92
Experimental Group_18	Experimental Group	8	Male	high	65	85	57	81	78	92
Experimental Group_19	Experimental Group	7	Male	high	74	80	74	81	63	97
Experimental Group_20	Experimental Group	6	Male	low	64	80	58	76	69	89
Experimental Group_21	Experimental Group	8	Male	low	65	92	69	78	72	92
Experimental Group_22	Experimental Group	9	Male	high	67	84	69	78	71	97
Experimental Group_2	Experimental Group	7	Male	high	78	98	58	78	70	95

3										
Experimental Group_24	Experimental Group	10	Male	high	69	87	60	80	67	91
Experimental Group_25	Experimental Group	7	Male	high	71	92	62	92	60	99
Control Group_1	Control Group	9	Male	low	64	77	64	65	68	75
Control Group_2	Control Group	8	Male	middle	67	78	65	71	60	83
Control Group_3	Control Group	10	Male	middle	73	73	55	79	78	77
Control Group_4	Control Group	10	Male	low	68	79	74	73	68	72
Control Group_5	Control Group	9	Male	middle	70	75	56	71	77	80
Control Group_6	Control Group	7	Male	low	70	80	66	75	78	75
Control Group_7	Control Group	6	Male	middle	60	70	65	70	77	74
Control Group_8	Control Group	6	Male	low	79	78	71	68	67	70
Control	Contr	6	Male	low	78	80	73	78	76	82

Group_9	ol Group									
Control Group_10	Control Group	10	Male	high	77	70	68	67	74	71
Control Group_11	Control Group	7	Male	low	77	83	60	67	63	70
Control Group_12	Control Group	10	Male	high	62	79	64	67	73	71
Control Group_13	Control Group	9	Male	high	77	76	62	65	62	77
Control Group_14	Control Group	8	Male	low	67	75	69	69	62	72
Control Group_15	Control Group	6	Male	high	67	71	57	72	73	77
Control Group_16	Control Group	8	Male	low	73	84	70	66	66	79
Control Group_17	Control Group	6	Male	low	78	82	73	68	77	71
Control Group_18	Control Group	6	Male	low	79	80	64	79	61	72
Control Group_19	Control Group	9	Male	low	64	75	63	66	71	72
Control Group_2	Control	9	Male	middle	71	77	71	74	73	76

0	Group									
Control Group_21	Control Group	6	Male	high	76	83	63	72	61	82
Control Group_22	Control Group	6	Male	low	70	83	58	74	72	71
Control Group_23	Control Group	10	Male	middle	77	74	64	68	68	75
Control Group_24	Control Group	7	Male	low	65	79	66	71	69	75
Control Group_25	Control Group	10	Male	low	65	80	62	66	71	82

N. Precise Design of the Experimental Scenarios

The experimental period lasts for 12 months. During this period, data collection proceeds in four quarters successively, and each quarter encompasses specific aspects. These include cognitive ability tests, which are mainly used to assess children's attention, memory, and problem-solving abilities; the behavioral observation part, which focuses on recording the interactive behaviors between children and natural elements; and environmental data monitoring, which collects relevant data such as the air quality (specifically PM2.5) and noise levels in the park.

O. Data Collection and Processing

1) *Types of Data*

Cognitive test data: Professional cognitive test tools are used to obtain data. For the attention test, the Stroop test is applied, with the reaction time and correct rate as the evaluation indicators. For the memory test, the n-back task is utilized, and the working memory score is used to measure it. Regarding the problem-solving ability, logical reasoning tasks are adopted, and the completion time and correct rate are used for evaluation. Trained personnel are arranged every quarter to conduct tests on the research subjects using unified test tools. The

final data are presented in the form of the average scores and standard deviations of children, with relevant references in [20].

Behavioral record data: A specially designed behavioral observation scale is used as a recording tool to record in detail the interactive task situations completed by children in various activities, such as the degree of meticulousness in observing plants, the types and quantities of biological collections, and the specific performances in water-friendly activities.

Environmental monitoring data: Portable PM2.5 monitors are used to monitor air quality and record the daily concentrations of airborne particulate matter. Noise recorders are used to collect the noise levels in the park, with the unit being decibels, so as to reflect the environmental conditions of the park. 4. Socioeconomic data: Relevant socioeconomic information of children's families is collected, including parents' education levels and family income status. And the SES grouping is carried out based on the quantile method to comprehensively analyze the relevant differences under different socioeconomic backgrounds.

2) Data Processing

Appropriate handling is carried out for the possible missing values in the cognitive test data to ensure the integrity and validity of the data. For behavioral data, in-depth analysis is conducted through video recordings and they are transformed into quantifiable indicators, such as the number of activities and the duration of activities, to facilitate subsequent statistical analysis. 2. Data standardization: All test results are standardized with z-scores to effectively eliminate the differences in measurement units among different test indicators, providing a scientific and accurate basis for cross-group comparisons and making the research results more comparable and reliable. 3. Data analysis tools: Python and SPSS, two professional software with powerful functions and widely used in the field of data analysis, are selected to conduct in-depth analysis and visualization processing of data to present the data characteristics and internal laws intuitively and clearly, with relevant operations referred to in [21].

3) *Data Analysis and Result Visualization*

Descriptive statistics regarding the sample distribution: The average age is 8.2 years (SD = 1.3). The p-values for the gender ratio and SES distribution between the Experimental Group and the Control Group are

all greater than 0.05, indicating that the grouping is balanced.

Table. 1.

variable	Experimental Group average (SD)	Control Group average (SD)	p 值
Attention Score	85.3 (6.2)	78.1 (5.8)	<0.01
Memory Score	76.4 (7.5)	68.9 (6.7)	<0.01
Problem-solving Score	89.2 (5.9)	82.7 (6.3)	<0.01

Difference Analysis： An independent-samples t-test was used to compare the cognitive test results of the Experimental Group and the Control Group. Results: The scores of the Experimental Group in the three dimensions of attention, memory, and problem-solving abilities were all significantly higher than those of the Control Group [22].

Table. 1.

Test Dimension	t – value	Degrees of Freedom	p – value
attention	3.54	118	<0.01
memory	4.62	118	<0.01
problem-solving ability	5.01	118	<0.01

Multivariate Regression Analysis： The potential impacts caused by socioeconomic status (SES) and environmental variables were effectively controlled. For this purpose, a specific analytical model was constructed: Cognitive score was set to be equal to β0 + β1 (natural element score) + β2 (SES) + β3 (air quality) + ε. Among them, β0 represents the constant term, β1, β2, and β3 are the regression coefficients corresponding to the natural element score, SES, and air quality respectively, and ε represents the random error term. Through a rigorous data analysis process, the obtained results showed that the natural element score had an extremely significant impact on the improvement of cognitive ability. Its regression coefficient β1 reached 0.42, and the p-value was less than 0.01 in a statistical sense. For detailed references, please see [23]. Meanwhile, the moderating effect of SES on cognitive ability also exhibited significant characteristics, with its regression coefficient β2 being 0.35 and the corresponding p-value being less than 0.05. This series of results provided solid data

support and a scientific basis for in-depth exploration of the complex mechanism of the roles of natural elements, SES, and environmental variables in the process of cognitive development, which was helpful for further promoting the in-depth expansion and theoretical deepening of research in related fields.

Mediating Effect of Environmental Data： The structural equation model (SEM) was adopted to analyze the indirect effects of natural elements on cognitive development through reducing air pollution and noise [24]. Results: The total effect of natural elements on cognitive ability was 0.58 ($p < 0.01$). Among them, the indirect effect through air quality was 0.22, and the indirect effect through noise was 0.15.

Data Visualization： The horizontal axis represents the time points of the experimental period (from T1 to T4), and the vertical axis represents the cognitive ability scores. Results: The cognitive ability of the Experimental Group improved significantly faster than that of the Control Group.

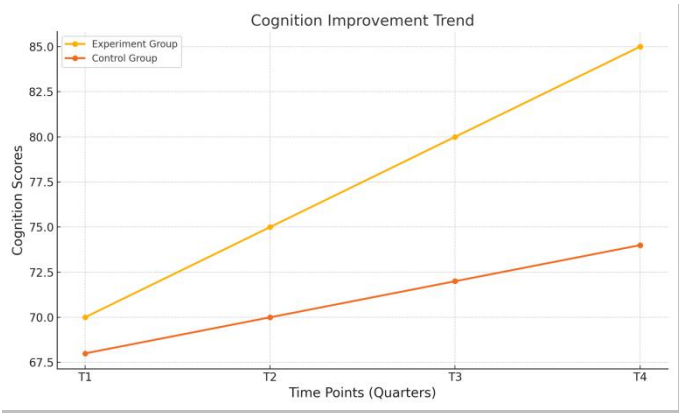

Fig.1. Figure 1: Trend Chart of Cognitive Ability Changes

The horizontal axis represents the scores of exposure to natural elements, and the vertical axis represents the scores of cognitive ability. Results: There is a significant positive correlation between the scores of exposure to natural elements and the scores of cognitive ability.

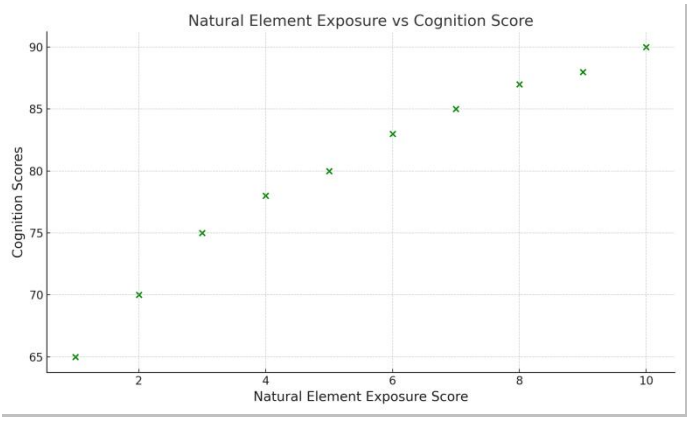

Fig.2. Figure 2: Scatter Plot of Natural Elements and Cognitive Scores

Compare the PM2.5 concentrations and noise levels between the experimental park and the control park.

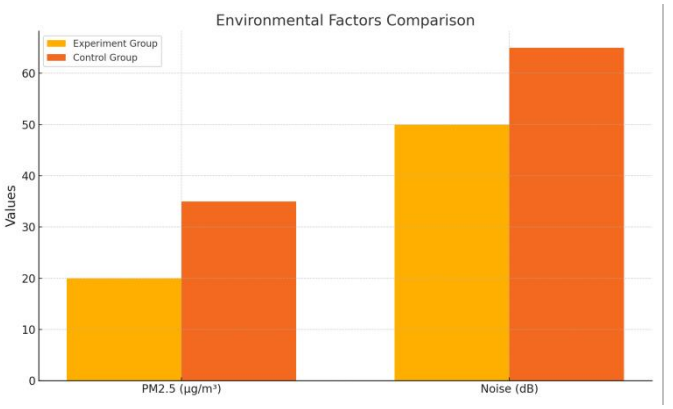

Fig.3. Figure 3: Bar Chart of Environmental Data Comparison

5. Results and Analysis

P. The Direct Promoting Effect of Natural Elements on Children's Cognitive Abilities

The experimental results of this study show that natural elements in the urban park environment have a significant positive promoting effect on children's cognitive abilities. Children in the Experimental Group showed significant improvements in multiple cognitive dimensions such as attention, memory, and problem-solving abilities. Compared with the Control Group, the p-values were all less than 0.01, indicating a highly significant statistical association between exposure to natural elements and the improvement of cognitive abilities. This finding is consistent with previous studies, suggesting that the natural environment can effectively stimulate children's sensory experiences, concentration, and

problem-solving abilities (Dadvand et al., 2015; Maes et al., 2021), and thus promote the overall improvement of their cognitive functions.

Q. The Indirect Promoting Effect of Environmental Improvement on Cognitive Abilities

In addition to the direct cognitive improvement effect, this study also found that natural elements have a significant indirect promoting effect on children's cognitive abilities by improving environmental quality (such as reducing PM2.5 concentrations and noise levels). The analysis of environmental data shows that the configuration of natural elements (such as plants, water bodies, and terrains) in the experimental park played a key role in reducing air pollution and noise interference, thereby improving children's cognitive performance. Relevant literature points out that the improvement of air quality can reduce physiological stress and enhance the brain's cognitive processing ability (Shanahan et al., 2019). This mechanism has been verified by this study, further expanding the scope of the influence of environmental factors on cognitive development.

R. The Moderating Role of Socioeconomic Status on the Effect of Natural Exposure

In this study, we introduced the variable of socioeconomic status (SES) to analyze its moderating role on the relationship between natural exposure and cognitive benefits. The results show that children with high SES have a more significant cognitive improvement after exposure to the natural environment. However, even among the low SES group, children can also obtain significant cognitive benefits from the natural environment. This finding is consistent with the research of Vanaken and Danckaerts (2018), indicating that natural exposure can not only make up for the disadvantages of low SES children in other development areas but also provide equal opportunities for cognitive improvement. This conclusion has important implications for the future design of inclusive child-friendly urban parks. In particular, more attention should be paid to the configuration of natural elements in the park planning of low SES communities.

S. The Cumulative Effect of Long-Term Natural Exposure

The cumulative effect of long-term exposure to natural elements has been verified in this study. The experimental results show that the promoting effect of an environment rich in natural elements on cognitive abilities gradually increases over time, especially in the later

stages of the experimental period (such as the T3 to T4 stage). This finding is consistent with Hartig et al.'s (2014) theory on the long-term benefits of natural exposure, indicating that continuous contact with nature can significantly enhance children's brain cognitive functions through the mechanism of neuroplasticity. Future research can further explore the multi-dimensional impacts of long-term exposure on children's social skills, emotional regulation, and behavioral performance, especially in complex urban environments.

T. Multidimensional Data Analysis and Statistical Modeling

This study adopted a multi-level analysis method, combining environmental monitoring data, cognitive test results, and socioeconomic variables to establish a statistical model for the improvement of cognitive abilities. Through multi-level regression analysis, we found that the natural element score has a significant positive impact on the improvement of cognitive abilities ($\beta1 = 0.42$, $p < 0.01$), and the moderating effect of SES on cognitive abilities is also significant ($\beta2 = 0.35$, $p < 0.05$). These results indicate that not only the configuration of natural elements is a key factor in cognitive development, but also socioeconomic factors play an important moderating role. This finding provides a solid theoretical basis for future interdisciplinary research and can more accurately evaluate the interaction between the natural environment and socioeconomic factors in improving cognitive abilities.

U. The Mediating Effect Analysis of Environmental Data

Through the structural equation model (SEM), this study further analyzed the mediating effect of natural elements on the improvement of cognitive abilities by improving air quality and reducing noise. The results show that the mediating effect of air quality improvement on cognitive abilities is 0.22, and the mediating effect of noise reduction is 0.15. Overall, the total effect of natural elements on cognitive abilities is 0.58 ($p < 0.01$). This finding expands the existing theoretical framework, indicating that environmental factors not only directly affect children's cognitive performance but also enhance their influence through mediating pathways, providing a new perspective for future research on environmental improvement and cognitive development.

V. Future Research Directions and Practical Significance

The results of this study not only provide empirical support for theoretical research but also offer practical guidance for the future

design of urban parks. To further enhance the promoting effect of the natural environment on children's cognition, future research can further expand the time span of the experiment and explore the interaction of different natural elements and their long–term impacts on children's multi–dimensional cognition. In addition, future policymakers and urban planners should pay more attention to the construction of the natural environment in low SES communities to achieve the dual goals of environmental equity and health promotion.

6. Discussion

W. The Core Role of Natural Elements in Promoting Cognitive Abilities

The results of this study show that urban parks rich in natural elements have a significant effect on promoting the improvement of children's cognitive abilities. Through multidimensional cognitive tests, it has been found that natural elements such as plants, water bodies, and terrains can directly stimulate children's sensory stimuli and exploratory behaviors, and then enhance their attention, memory, and problem–solving abilities. This finding not only verifies the theoretical framework of environmental psychology regarding the restorative power of nature but also systematically quantifies for the first time the differential effects of combinations of natural elements on different cognitive dimensions. This innovative analysis provides more detailed guidance for the design of the natural environment and fills the gap in previous studies regarding the discussion on the combined effects of multidimensional natural elements [25].

X. The Indirect Promoting Effect of Environmental Improvement on Cognitive Abilities

The study further reveals that natural elements have a significant indirect promoting effect on children's cognitive abilities by reducing PM2.5 concentrations and noise levels. This mechanism analysis theoretically deepens the understanding of the benefits of the natural environment, expanding the traditional perspective of direct effects to a more complex mediating effect model. Meanwhile, this finding also provides a new practical direction for environmental governance and the construction of green spaces in urban planning: by optimizing the distribution of natural elements and improving the quality of the micro–

environment, the physical and mental development of children can be promoted more widely [26].

Y. The Moderation of Socioeconomic Status on the Effect of Natural Exposure

The advantage of high SES children in the improvement of cognitive abilities shows that socioeconomic resources affect the effect of natural exposure. However, this study also found that children with middle–low SES can also benefit significantly. This result has important social significance, indicating that by designing fairer opportunities for natural contact, the negative impact of socioeconomic inequality on children's cognitive development can be effectively reduced. This conclusion further echoes the core issues of social equity and public health policies and provides empirical support for the common development of different groups [27].

Z. The Cumulative Effect of Long–Term Natural Exposure

The study found that the benefits of exposure to natural elements gradually increase over time. This long–term effect verifies the continuous role of the natural environment in children's development. In particular, the rapid improvement in cognitive abilities in the Experimental Group from the T3 to T4 stage indicates that long–term and stable contact with nature can significantly amplify the benefits of natural elements. This finding expands the time limitation of previous short–term studies and provides a solid foundation for subsequent research on the continuity of natural exposure [28].

AA. The Innovative Contribution of Interdisciplinary Research Methods

This study adopted randomized controlled experiments, structural equation models, and multi–level analysis methods to systematically evaluate the complex relationships among natural elements, environmental improvement, and cognitive abilities. This interdisciplinary research method combining behavioral experiments, environmental monitoring, and quantitative analysis not only improves the scientific nature of the research results but also provides a reproducible paradigm for subsequent research. Different from previous studies that mainly relied on observational designs, the experimental design of this study effectively enhances the ability of causal inference and significantly raises the theoretical height of the research [29]. 6.6 Implications for the Design of Future Green Spaces The results of the

study are of great significance for optimizing the design of green spaces. For example, combinations of different natural elements can be customized according to the multidimensional needs of children. Meanwhile, by considering socioeconomic variables, the green space coverage in low SES communities can be further increased in park planning to maximize the impact of the natural environment on public health. This innovative insight provides a theoretical basis and practical guidance for the planning of urban green spaces in the future [30].

7. Conclusion

Through the multi-level data analysis and modeling in this study, combined with the results of environmental monitoring and cognitive testing, the direct and indirect influence pathways of the natural environment on children's cognitive development have been revealed, providing valuable theoretical basis for future research. The achievements of this study not only offer scientific basis for optimizing the design of child-friendly urban parks but also provide strong support for policymakers in promoting the construction of green spaces, improving public health and facilitating social equity. In general, this study provides a new perspective for understanding the mechanism of the role of natural elements in children's cognitive development. Future research should further explore the optimal configuration of different combinations of natural elements, the applicability across regions and cultures, as well as the comprehensive effects of long-term natural exposure on children's physical and mental development.

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