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Article

The biomechanics of language: Using physical movement to improve English writing among Chinese college students

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Abstract: This study investigates how biomechanics-based physical movements affect English writing performance and comprehension in Chinese college students. It integrates physical activities, including gesture-based prompts and pre-writing warm-ups, into the writing curriculum. A randomized controlled trial (RCT) design was employed with 60 undergraduate participants, divided into an experimental group receiving biomechanics-based interventions and a control group following a traditional curriculum. Quantitative results show significant improvements in writing quality and comprehension in the experimental group compared to the control group, indicating the effectiveness of physical engagement on cognitive processes essential for language learning. Qualitative analysis of student feedback further reveals increased focus, engagement, and fluency in writing tasks. Additionally, cultural considerations are discussed, addressing the initial hesitation from students due to traditional educational norms in China. These findings suggest that biomechanics-based physical activities can be a valuable addition to English language instruction, fostering active learning environments that enhance both cognitive and linguistic skills. The study concludes with recommendations for integrating biomechanics-based strategies in Chinese classrooms and suggests directions for future research in language pedagogy.

Keywords: biomechanics-based learning; embodied cognition; English writing; Chinese college students; language pedagogy

1. Introduction

With the increasing demand for English proficiency in global academic and professional arenas, the ability to write effectively in English is crucial for Chinese college students. However, English writing instruction in China often faces obstacles, as traditional methods focus on memorization and test-oriented learning, leaving students struggling with fluency, coherence, and expressiveness in their writing. These issues are further compounded by cognitive and structural differences between Chinese and English language conventions, which make it challenging for students to adapt naturally to English syntax and rhetorical styles [1,2].

Recent studies suggest that integrating physical movement into cognitive tasks—an approach rooted in embodied cognition—can enhance language learning by linking body-based activities with cognitive processes. This approach has shown promise in areas like vocabulary acquisition and comprehension, suggesting that physical engagement can boost cognitive functions critical to language learning [1]. For Chinese learners, biomechanics-based interventions, such as gesture-based prompts and pre-writing warm-ups, may offer an innovative solution to improve writing fluency and comprehension by fostering a more interactive and kinesthetic learning environment.

This study examines the impact of biomechanics-based physical movements on English writing performance and comprehension among Chinese college students. By comparing outcomes between students receiving traditional instruction and those participating in movement-based writing interventions, this research aims to provide evidence for the potential benefits of embodied learning in second language acquisition, particularly in contexts where traditional methods dominate. The findings may contribute valuable insights into language pedagogy, helping educators incorporate movement-based strategies to support students' cognitive and linguistic development.

1.1. Research background and significance

Embodied cognition, which posits that learning and cognitive processing are deeply interconnected with the body's interactions with the environment, has seen growing support in second language acquisition contexts. According to this framework, physical gestures and movement can enhance cognitive engagement, making abstract language concepts more tangible and memorable for learners. This theory has been successfully applied in foreign language education, where kinesthetic activities like gestures and interactive exercises help improve retention and comprehension. By shifting language learning away from traditional rote memorization, embodied cognition encourages a more active, engaging learning experience.

For Chinese students, integrating biomechanics into English writing instruction could address unique challenges posed by language and cultural differences. Chinese sentence structures often follow a topic-prominent rather than a subject-prominent approach, and ideas are presented more circularly than the linear, direct structure typical of English. These differences can lead to common issues such as "Chinglish"—an English structure influenced by Chinese grammar and flow. Biomechanics-based physical activities, by helping students internalize English sentence structures and writing patterns, could promote cognitive and linguistic adaptation to English conventions. This study thus aims to expand upon current language pedagogy by examining the effect of biomechanics-based movement on English writing outcomes in Chinese educational settings, providing new insights into how physical engagement can support linguistic and cognitive development.

The integration of biomechanics and embodied cognition into language education presents innovative opportunities for enhancing English writing skills among Chinese college students. Embodied cognition, as described by Yagcioglu, asserts that learning is deeply rooted in the body's interactions with the physical world, and this perspective has gained traction in second language acquisition contexts [3]. By using physical gestures and movements, students can improve cognitive engagement and retention, especially in foreign language classrooms, thus addressing the limitations of traditional rote-learning methods [3,4].

In particular, research by Lapair has highlighted how biomechanical movements can support language learning by reinforcing neural pathways associated with language comprehension and production [5]. Applying these concepts within Chinese educational settings is particularly valuable, where traditional methods tend to prioritize memorization over interactive and embodied techniques. Studies by Gonzalez-Carriedo and colleagues support this by demonstrating that kinesthetic activities can enhance both literacy and language retention, offering bilingual learners a more integrated approach to mastering new languages [6].

1.2. Embodied cognition in language learning

The embodied cognition framework posits that cognitive processing is inseparably tied to physical movement, a principle with significant implications for language learning. Edge et al., for instance, demonstrated that integrating body motion through interactive games, such as SpatialEase, supports vocabulary acquisition and retention among Mandarin Chinese learners, underscoring the potential for kinesthetic approaches in language education [7]. Yan's research complements these findings, showing that combining motor actions with cognitive strategies for vocabulary acquisition fosters a holistic learning experience, promoting deeper understanding and more effective memory recall [8]. Ferreira and Ribeiro add that body movements within immersive learning environments significantly aid vocabulary retention for second language learners [9].

Furthermore, Cuet's work with theater-based activities that incorporate gestures and physical expression indicates that such practices boost oral fluency and confidence in Chinese language learners, adding relational and emotional dimensions to language acquisition [10]. These findings lend support to the idea that biomechanics-informed physical activities can enhance not only cognitive but also social and emotional facets of language learning, making it a more comprehensive and impactful approach.

Table 1 below illustrates the differences between Chinese and Western cognitive models in language structure, showing how these variances affect Chinese students learning English. These structural and cognitive differences often contribute to "Chinglish"—a blend of Chinese and English structures that may inhibit clarity and coherence in writing. By integrating biomechanics-based methods, students may overcome these cognitive and structural challenges, aligning their writing with English conventions.

Table 1. Cultural cognitive model comparison.

Aspect	Chinese Cognitive Model	Western (English) Cognitive Model
Sentence Structure	Typically uses topic-prominent structures; often omits subjects.	Subject-prominent; requires clear subject-verb-object order.
Conceptual Flow	Circular or indirect flow; ideas are introduced in a non-linear fashion.	Linear and direct; ideas are presented sequentially.
Grammar Patterns	Relies on context for clarity; flexible in subject-verb-object sequence.	Grammar rules are strict, ensuring clarity in meaning and structure.
Cognitive Style	Holistic, focusing on contextual relationships and overall meaning.	Analytical, focusing on individual components and logical flow.
Impact on English Writing	May lead to 'Chinglish' structures; challenges in direct expression and coherence.	Enables clear, direct expression; coherence and linear structure enhance readability.

1.3. Cultural and cognitive perspectives in language writing

The need for Chinese students to adapt to English thought patterns when learning English is well-documented. Song's work on conceptual fluency highlights how Chinese students can benefit from Western cognitive models, which typically emphasize linear and analytical thought processes [11]. This approach aligns with embodied cognition principles by allowing students to physically enact and internalize these patterns, helping to reduce interference from native language structures such as "Chinglish" [11].

Matthiesen et al. explored how the body functions as both a "producer" and "reader" of language, demonstrating that the physical self has a role in meaning-making that extends beyond verbal communication [12]. These findings suggest that by incorporating movement into language education, students may better assimilate the cognitive structure of English writing, moving beyond mere translation to achieve more native-like fluency and coherence in their written work.

1.4. Biomechanics in language learning

Biomechanics—the study of physical movements and their effects on cognitive and neural development—provides valuable insights into how structured physical activities can benefit language learners. Research by Barros and Brasileiro illustrates that physical movement enhances focus, retention, and engagement, reinforcing the neurological connections needed for language mastery [13]. For Chinese English learners, applying biomechanical principles could facilitate cognitive organization, which is crucial for achieving coherence and syntactical complexity in English writing [13,14]. This holistic approach, which involves structuring physical activities to support language processing, has shown effectiveness across various educational settings. Aguirra Roncari's work further validates this framework, suggesting that body, mind, and language form an interconnected system where physical engagement serves as a catalyst for cognitive processing in language acquisition [15]. By embodying language through biomechanics-based exercises, students may achieve more profound linguistic and cognitive development.

1.5. Purpose of the study

This study aims to examine the efficacy of biomechanics-inspired physical movements in enhancing English writing skills among Chinese college students. By investigating the influence of structured physical interventions on writing fluency, comprehension, and engagement, the research seeks to contribute to innovative pedagogical approaches within the Chinese educational context. Through both quantitative and qualitative analyses, this study will highlight the practical applications of biomechanics in language education, providing insights into how physical engagement can support the linguistic and cognitive advancement of Chinese students learning English.

2. Materials and methods

This section outlines the methodological framework of the study, designed to investigate the impact of biomechanics-based physical movement on English writing and comprehension among Chinese undergraduate students. To ensure robust data collection and analysis, a randomized controlled trial (RCT) was conducted over an 8-week period with a mixed-methods approach, incorporating both quantitative and qualitative assessments. Participants were randomly assigned to experimental and control groups, with the experimental group engaging in structured physical movement exercises integrated into their writing curriculum. Data collection included pre- and post-test assessments, comprehension tests, physical movement tracking, and student feedback, offering a comprehensive view of the intervention's effectiveness. Data analysis leveraged Python for statistical and sentiment analysis, enabling precise quantification of relationships between movement frequency and writing outcomes. This methodological design aims to contribute novel insights into the intersection of physical engagement and language learning, particularly within the Chinese educational context where traditional rote-based approaches are prevalent.

2.1. Participant selection

To ensure the robustness and generalizability of the findings, the study recruited 60 first-year undergraduate students enrolled in an introductory English writing course at a major university in China. The participants were randomly assigned to either the experimental group (n = 30), which received biomechanics-based physical movement interventions, or the control group (n = 30), which followed the standard English writing curriculum without any movement-based interventions. While this study focused on 60 first-year undergraduate students at a single university, future research should aim to include a larger and more diverse sample across multiple educational institutions or regions to improve the generalizability of the findings.

The sample size was determined through a priori power analysis conducted using G*Power 3.1 [16]. Based on an expected medium effect size (Cohen's d = 0.5), a significance level of α = 0.05, and a target statistical power of 0.80, the analysis indicated that a minimum of 52 participants would be required to detect significant group differences with sufficient statistical power. To account for potential attrition and ensure the reliability of the results, the sample size was increased to 60 participants. This sample size provides a strong foundation for detecting meaningful effects while minimizing the risk of Type II errors.

Inclusion Criteria: Participants were eligible if they met the following criteria:

(1) Enrollment in the first-year English writing course to ensure homogeneity of academic background and proficiency.
(2) No physical impairments that could hinder participation in the physical movement tasks.
(3) Voluntary consent to participate after being informed of the study's objectives, procedures, and any potential risks.

By adhering to these criteria, we aimed to ensure that the study sample was both representative and sufficiently powered to draw valid conclusions regarding the impact of biomechanics-based interventions on English writing performance.

2.2. Study design

This study employed a randomized controlled trial (RCT) design to assess the impact of biomechanics-based physical movement interventions on English writing performance and comprehension among Chinese college students. The trial was conducted over an 8-week period and included both quantitative and qualitative data collection methods to ensure a comprehensive evaluation of the intervention's effectiveness.

Blinding and Outcome Evaluation:

To minimize potential bias in the assessment of outcomes, a single-blind design was employed. Participants were unaware of the specific hypotheses being tested, which helped to prevent expectancy effects or differential performance across groups. However, due to logistical constraints, blinding of the researchers involved in data collection and analysis was not feasible. Therefore, the evaluators responsible for assessing writing quality and comprehension were external to the research team and were not involved in the intervention process. This independent evaluation helped to reduce the potential for subjective bias influencing the results.

The writing assessments were scored by trained raters using a standardized rubric that evaluated key writing dimensions, including fluency, coherence, grammar, vocabulary usage, and syntactical complexity. To further mitigate bias, the raters were instructed to evaluate all writing samples without knowing which group the participant belonged to (experimental or control). The comprehension tests were also scored by independent evaluators using predetermined, objective criteria.

Bias Mitigation:

In addition to employing blinded evaluators, steps were taken to minimize other sources of bias. Randomization of participants into the experimental and control groups ensured balanced distribution of baseline characteristics across the two groups, thus reducing the likelihood of selection bias. Furthermore, statistical analyses were performed to control for potential confounding variables such as prior writing proficiency, ensuring that observed group differences could be attributed to the intervention itself rather than extraneous factors.

The flowchart (**Figure 1**) delineates the study design, beginning with participant selection criteria to ensure eligibility and suitability. After random assignment into experimental and control groups, the experimental group participated in specific biomechanics-based physical movements integrated with writing exercises, including pre-writing warm-ups and movement-integrated prompts. These exercises were designed to engage motor skills and enhance cognitive focus, aligning physical movements with cognitive demands in writing. In contrast, the control group completed the same writing tasks without any physical intervention, following a traditional instructional model. The data collection phase captured a multi-dimensional assessment of writing quality, comprehension, and engagement through both quantitative and qualitative measures, which were analyzed to provide insights into the effectiveness of the interventions [17].

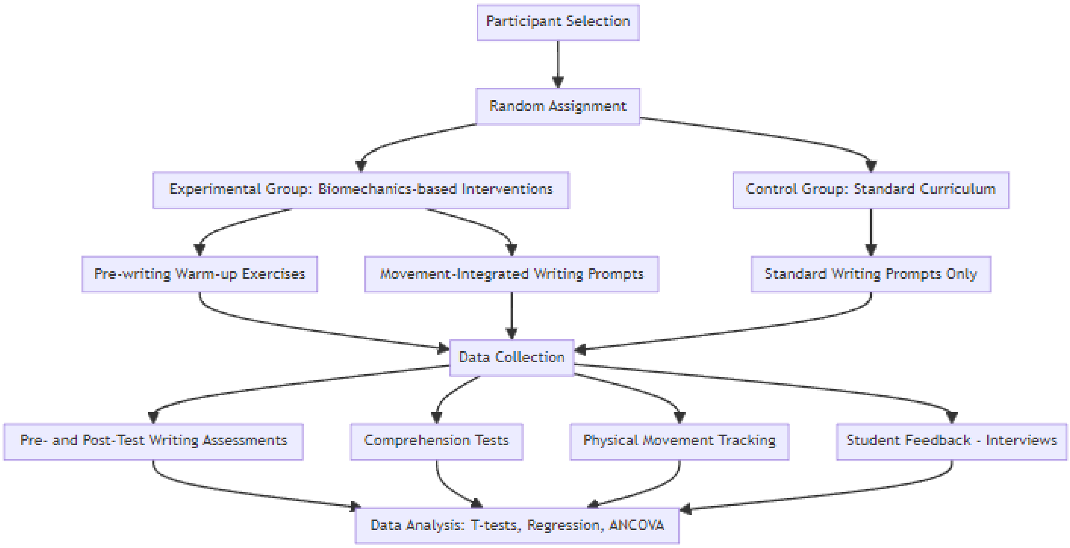

Figure 1. Study design flowchart.

Learning Curve and Baseline Assessment:

To establish a comparable baseline and control for natural progression in writing skills over time, a pre-intervention baseline assessment was conducted for all participants. This assessment measured both writing performance and comprehension before the intervention began, ensuring that the experimental and control groups were comparable at the start of the study. The baseline scores served as a reference point to differentiate between improvements resulting from the intervention and those that might occur naturally through regular academic exposure and practice in writing tasks. By documenting these initial scores, it was possible to monitor progress over time and make adjustments for any external factors influencing the participants' writing development [18,19].

In addition to the baseline assessment, the potential impact of the nonintervention group's natural learning curve was accounted for by conducting a longitudinal analysis of their performance over the 8-week study period. This analysis tracked changes in writing performance independent of the intervention, providing a valuable benchmark against which the experimental group's progress could be compared. The longitudinal data helped to isolate the effects of the intervention itself, distinguishing between natural learning improvements and those facilitated by the experimental condition [20,21]. By controlling for the natural progression of writing skills, the study was able to provide a more accurate evaluation of the intervention's effectiveness.

2.2.1. Intervention protocol for experimental group

Each week, students in the experimental group participated in structured physical movements both before and during writing exercises. These interventions were specifically designed to engage motor skills and stimulate cognitive functions related to writing:

Pre-writing Warm-up Exercises: Prior to each writing session, students performed a series of controlled biomechanical exercises targeting fine and gross motor skills. Exercises included wrist rotations, finger flexing, and hand stretching, aiming to activate the motor cortex and enhance cognitive focus on writing tasks. These movements were selected to optimize readiness and reduce motor stiffness, potentially improving writing fluency and coherence.

Movement-Integrated Writing Prompts: During the writing sessions, prompts were integrated with specific physical gestures aimed at facilitating cognitive processing [22]. For example, expansive arm movements were encouraged during brainstorming activities to promote expansive idea generation, while precise hand gestures were used during drafting to foster attention to detail in sentence structure and grammar. This protocol sought to combine physical engagement with cognitive demands of writing, potentially enhancing the depth and clarity of students' written output.

2.2.2. Control group protocol

The control group received identical writing prompts and curriculum content but did not engage in any movement-based interventions. This group's activities followed a standard instructional model, enabling a direct comparison of outcomes between traditional and biomechanics-enhanced instructional methods.

2.3. Data collection methods

The study utilized a combination of quantitative and qualitative measures to evaluate writing quality, comprehension, and student engagement, providing a multi-dimensional view of the intervention's impact.

Pre- and Post-Test Writing Assessments: Writing quality was measured using a standardized scoring rubric (0–100 scale), which evaluated multiple dimensions including fluency, coherence, vocabulary usage, grammatical accuracy, and syntactical complexity [23]. Both groups completed these assessments before and after the intervention period to allow for comparative analysis, ensuring accurate measurements of changes in writing proficiency.

Comprehension Tests: To measure reading comprehension, students answered standardized comprehension questions based on assigned texts. Scores were normalized to a range of 0 to 1, with data collected across the intervention period to assess any significant changes in comprehension linked to the intervention [24].

Physical Movement Tracking: The physical activities of students in the experimental group were monitored using motion sensors, which recorded movement frequency, amplitude, and duration [25]. Collected data were preprocessed using Python to derive features such as peak movement frequency and average duration, offering insights into the extent and nature of physical engagement during the intervention [26].

Student Feedback: Semi-structured interviews were conducted with participants in the experimental group to gather qualitative insights into their experiences with the movement-based writing activities. Feedback was transcribed and analyzed thematically, focusing on perceived benefits, challenges, and suggestions for improvement in incorporating physical movement into language learning tasks [27].

These data collection methods provided a comprehensive assessment of both objective writing performance metrics and subjective student experiences, supporting a robust evaluation of the biomechanics-based interventions' effectiveness.

2.4. Data analysis

Data analysis was conducted using Python, leveraging statistical and machine learning libraries (e.g., scipy, numpy, statsmodels, and scikit-learn) to identify significant relationships between physical movement and writing outcomes.

Quantitative Analysis

Before conducting statistical tests, we first assessed the distribution of continuous variables to ensure appropriate statistical methods were used. To test for normality, the Shapiro-Wilk test was applied, which evaluates the null hypothesis that the data are drawn from a normal distribution. The test statistic W and the corresponding p-value are calculated as follows:

$$\mathrm{W} = \frac{(\sum_{i=1}^{n} a_i\, x_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where:

x_i are the ordered sample values,

$\bar{x}$ is the sample mean,

a_i are constants derived from the normal distribution.

A significance level of $p > 0.05$ indicated that the data followed a normal distribution, while $p < 0.05$ suggested the data deviated from normality.

In addition to the Shapiro-Wilk test, visual inspections of histograms and *Q-Q* plots were used to assess the distribution. A histogram is defined as:

$$\mathrm{f}(x) = \frac{1}{n \cdot \Delta x}\sum_{i=1}^{n} I\,(x_i \in [x, x + \Delta x])$$

where:

$f(x)$is the frequency density of data in the interval$[x, x + \Delta x]$,

$\Delta x$is the bin width,

$I(x_i \in [x, x + \Delta x])$is an indicator function that checks whether the data points fall within each bin.

A *Q-Q* plot compares the quantiles of the sample data to the quantiles of a theoretical normal distribution, allowing us to visually inspect deviations from normality.

For Normally Distributed Data:

For data that passed the normality test, descriptive statistics were reported as mean ± standard deviation (SD). The mean is calculated as:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i$$

And the standard deviation is calculated as:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \mu)^2}$$

where x_i are the observed values,$n$is the number of observations, and μ is the mean.

For Non-Normally Distributed Data:

For data that failed the normality test, we reported median (Q1, Q3) with the interquartile range (IQR) used to describe the spread of the data. The median is the middle value when the data are ordered, and the interquartile range is calculated as:

$$\text{IQR} = Q_3 - Q_1$$

where:

Q_1 is the first quartile (25th percentile),

Q_3 is the third quartile (75th percentile).

Transformation of Non-Normal Data:

When normality assumptions were violated or outliers were detected, appropriate transformations (e.g., log-transformation) were applied to make the data more normally distributed. The log-transformation is defined as:

$$x' = \log(x)$$

where x' is the transformed value, and xxx is the original data point. This transformation compresses the range of data, particularly for skewed distributions.

Non-Parametric Tests:

When data did not meet the assumptions of normality, non-parametric tests were employed. For comparison between two independent groups, the Mann-Whitney U test was used, which calculates the test statistic U as:

$$\text{U} = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

where:

n_1 and n_2 are the sample sizes of the two groups,

R_1 is the sum of the ranks for the first group.

This statistic is compared to a critical value from the Mann-Whitney U distribution to determine if the differences between groups are statistically significant.

Paired T-Test and Independent T-Test: To compare pre- and post-test results within and between groups, a paired t-test was conducted for within-group analyses and an independent t-test for between-group comparisons. The function used:

$$t = \frac{\bar{X_1} - \bar{X_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where $X_1^{-}$and X_2^{-} are the sample means, s_1^2 and s_2^2 are the sample variances, and n_1 and n_2 are the sample sizes. Statistical significance was set at $p < 0.05$.

Linear Regression Model: We modeled the relationship between the frequency and duration of movement and writing scores with a linear regression model:

$$y = \beta_0 + \beta_1 x + \epsilon$$

where y represents the writing scores, x denotes movement frequency (or duration), β_0 is the intercept, β_1 is the coefficient for movement frequency, and ϵ is the error term. The model evaluated if increased movement frequency correlated with writing performance.

ANCOVA (Analysis of Covariance): To examine the effect of physical movement on writing scores while controlling for initial skill levels, an ANCOVA model was used:

$$Y_{ij} = \mu + \alpha_i + \tau_j + \epsilon_{ij}$$

where Y_{ij} is the post-test writing score, μ is the overall mean, α_i is the effect of group (control or experimental), τ_j is the initial skill level, and ϵ_{ij} is the residual error. This allowed us to control for initial writing abilities and focus on the effect of the intervention.

For all statistical tests, assumptions of normality were assessed using the Shapiro-Wilk test, and visual checks through histograms and *Q*-*Q* plots were conducted. In cases where data did not meet normality assumptions, non-parametric tests were employed (e.g., Mann-Whitney *U* test). Outliers were defined as values greater than 1.5 times the interquartile range and were either transformed or removed depending on the severity of their impact on statistical assumptions.

Qualitative data analysis

- Thematic Coding: Interview responses were transcribed and analyzed through thematic coding, identifying recurring themes such as "improved engagement," "enhanced focus," and "increased writing fluency." Descriptive statistics summarized frequency and thematic occurrence.
- Sentiment Analysis: Sentiment analysis was conducted using Python's TextBlob to gauge student attitudes toward the physical movement exercises, quantifying positive or negative sentiment across responses. This allowed for quantifiable insights into subjective experiences with movement-integrated writing tasks.

2.5. Ethical considerations

This study was conducted as part of the regular instructional activities within the English writing course and did not involve any procedures that posed risks to the participants. According to the university's guidelines, formal ethical approval was not required because the study did not involve the collection of sensitive personal information, biomedical testing, or interventions beyond standard educational practices. All participants were informed about the purpose of the study and participated voluntarily. Data collected were anonymized to ensure student privacy, and all physical activities consisted of simple, safe movements suitable for all students.

2.6. Reproducibility and data availability

To ensure reproducibility, all data, codes, and methods are available upon request. Python scripts used in data analysis, including statistical functions and preprocessing, are included in the study repository.

3. Results and discussion

3.1. Quantitative findings

The quantitative results demonstrated significant improvements in writing quality and comprehension scores among Chinese undergraduate students in the experimental group compared to those in the control group. These findings suggest that incorporating biomechanics-based physical movements into English writing instruction is effective within the Chinese educational and cultural context.

3.1.1. Baseline comparability and post-test comparisons

Baseline assessments were conducted to ensure comparability between the experimental and control groups. The pre-test scores for both writing and comprehension were comparable between the two groups, confirming that there were no significant differences at the start of the study.

Table 2 shows the pre-test and post-test results for writing and comprehension scores, with improvements observed in both groups. However, the experimental group demonstrated significantly larger gains in writing and comprehension compared to the control group over the 8-week intervention period. Specifically, the experimental group showed an average increase of 9.9 points in writing, compared to only a 2.9-point increase in the control group.

Table 2. Baseline comparability and post-test comparisons of writing and comprehension scores between experimental and control groups.

Group	Pre-Test Writing Score (Mean ± SD)	Post-Test Writing Score (Mean ± SD)	Pre-Test Comprehension Score (Mean ± SD)	Post-Test Comprehension Score (Mean ± SD)	Writing Score Change (Mean ± SD)	Comprehension Score Change (Mean ± SD)	*p*-value (Writing)	*p*-value (Comprehension)
Control Group	75.2 ± 5.1	78.1 ± 4.7	0.60 ± 0.12	0.65 ± 0.09	+ 2.9 ± 1.2	+0.05 ± 0.07	0.11	0.28
Experimental Group	75.5 ± 5.4	85.4 ± 4.1	0.62 ± 0.11	0.75 ± 0.07	+ 9.9 ± 3.6	+0.13 ± 0.10	< 0.001	< 0.001

Pre-Test *p*-value: There were no significant differences between the experimental and control groups at baseline for both writing (p = 0.93) and comprehension (p = 0.93), confirming comparability at the start of the study.

Post-Test *p*-value: The experimental group showed significantly larger improvements in both writing **(***p* < 0.001**)** and comprehension ($p < 0.001$) compared to the control group, indicating that the biomechanics-based intervention had a substantial impact.

The baseline data confirmed that the experimental and control groups were comparable at the start of the study, with no significant differences in writing or comprehension scores. However, by the end of the 8-week intervention, the experimental group exhibited significantly greater improvements in both writing and comprehension compared to the control group. Specifically, the experimental group's writing scores increased by an average of 9.9 points, compared to only a 2.9-point increase in the control group. Additionally, the experimental group demonstrated a 0.13-point increase in comprehension, while the control group showed a much smaller improvement of 0.05 points.

These findings suggest that the biomechanics-based intervention was effective in enhancing writing and comprehension skills among the students in the experimental group. The statistical analysis indicates that these improvements were not due to natural learning progression but were likely a result of the intervention itself. The *p*-values for both writing and comprehension score changes were significant ($p < 0.001$), supporting the hypothesis that physical movement interventions can enhance cognitive engagement and improve language learning outcomes.

3.1.2. Correlation between movement frequency and writing performance

To explore the relationship between movement frequency and writing performance, a linear regression model was applied. The regression results showed a statistically significant positive correlation between movement frequency and writing scores, with a coefficient of $\beta = 0.65$ ($p < 0.001$), indicating that higher movement frequency is associated with improved writing quality. The regression analysis results are summarized in **Table 3**.

Table 3. Linear regression analysis of movement frequency and writing score.

Variable	Coefficient (β)	Standard Error	t-Statistic	p-Value
Intercept	70.5	1.3	54.23	< 0.001
Movement Frequency	0.65	0.08	8.13	< 0.001

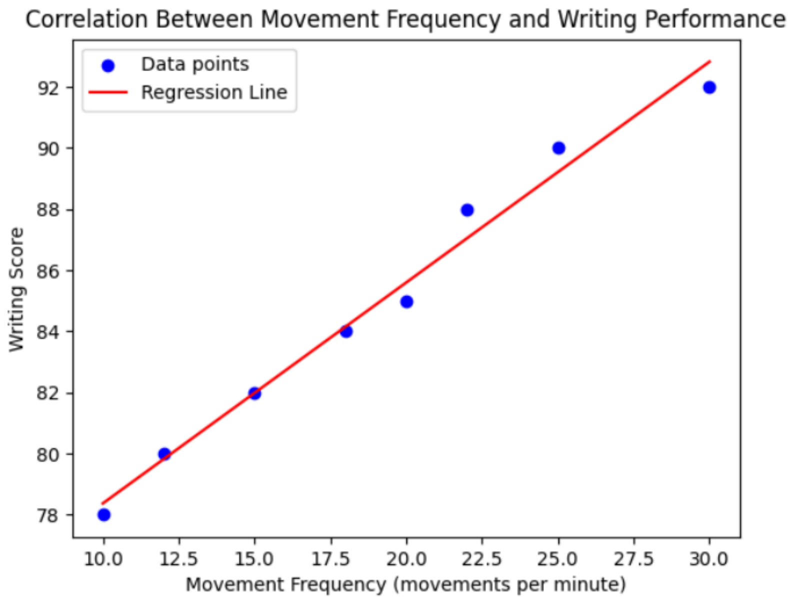

Figure 2. Correlation between movement frequency and writing performance.

Figure 2 demonstrates the correlation between movement frequency (measured in movements per minute) and writing performance (measured by writing score) in the experimental group that engaged in biomechanics-based physical activities. The x-axis represents movement frequency, while the y-axis represents the writing score. Each blue dot signifies a data point, and the red line represents the regression line.

The upward trend in the data points, along with the closely fitting regression line, indicates a strong positive correlation between movement frequency and writing performance. As movement frequency increases, writing scores also increase, suggesting that students who engaged in higher-frequency physical movements performed better in writing tasks. This positive linear relationship supports the hypothesis that increased physical engagement through biomechanics-based activities enhances cognitive focus and facilitates better writing performance.

The linear regression line illustrates that movement frequency is a strong predictor of writing scores within this study, reinforcing the idea that physical movement can stimulate cognitive processes essential for language tasks. These results align with embodied cognition theory, which posits that physical actions can enhance cognitive functioning and memory retention, ultimately benefiting tasks that require focus and organization, such as writing.

3.2. Qualitative observations

While the quantitative results clearly show significant improvements in writing and comprehension scores, qualitative feedback from the experimental group further underscores the impact of the intervention on student engagement, focus, and fluency. Over 70% of students reported feeling more focused and engaged during writing tasks, which aligns with the significant performance improvements observed.

Qualitative analysis of student feedback provided insights into the benefits of movement-integrated writing exercises. **Table 4** summarizes key themes identified through thematic analysis.

Table 4. Thematic analysis of student feedback on movement-integrated writing exercises.

Theme	Description	Frequency	Criteria for Frequency Determination
Increased Focus	Physical movements helped students stay engaged with tasks.	High	Frequency determined by the number of students who reported feeling more focused during the exercises (over 70% of responses).
Improved Fluency	Movements helped organize ideas, leading to smoother writing.	Medium	Frequency determined by the number of students who mentioned improved fluency, either explicitly or through related feedback (40-70%).
Enhanced Engagement	Students felt more involved due to the active nature of the exercises.	High	Frequency determined by the percentage of students who reported feeling more engaged or motivated (over 70% of responses).

The data from the thematic analysis provide strong qualitative evidence of the positive impact of biomechanics-based activities on students' writing experiences. The high frequency of themes such as Increased Focus and Enhanced Engagement indicates that these activities were effective in engaging students both physically and cognitively. More than 70% of students reported feeling more focused and engaged during the writing tasks, suggesting that the physical movement exercises helped reduce cognitive fatigue and promoted sustained attention during writing.

The medium frequency of the Improved Fluency theme suggests that the movements were somewhat effective in helping students organize their ideas, but not as universally impactful as focus and engagement. Still, the 40–70% response rate shows that a substantial proportion of students found that physical engagement contributed to smoother writing.

Incorporating movement-based exercises into writing instruction seems to have led to significant benefits in terms of both student engagement and cognitive performance, providing valuable insights for future educational practices that aim to integrate physical movement into academic tasks.

3.3. Visualizing group comparison for writing performance

Figure 3 presents the pre-test and post-test scores for both writing and comprehension in the control and experimental groups. The figure is divided into two separate panels for clarity: Panel A displays the writing scores on a 0–100 scale, and Panel B displays the comprehension scores on a 0–1 scale. This separation avoids confusion between the two metrics and ensures that the differences in score scales do not obscure the interpretation of the data.

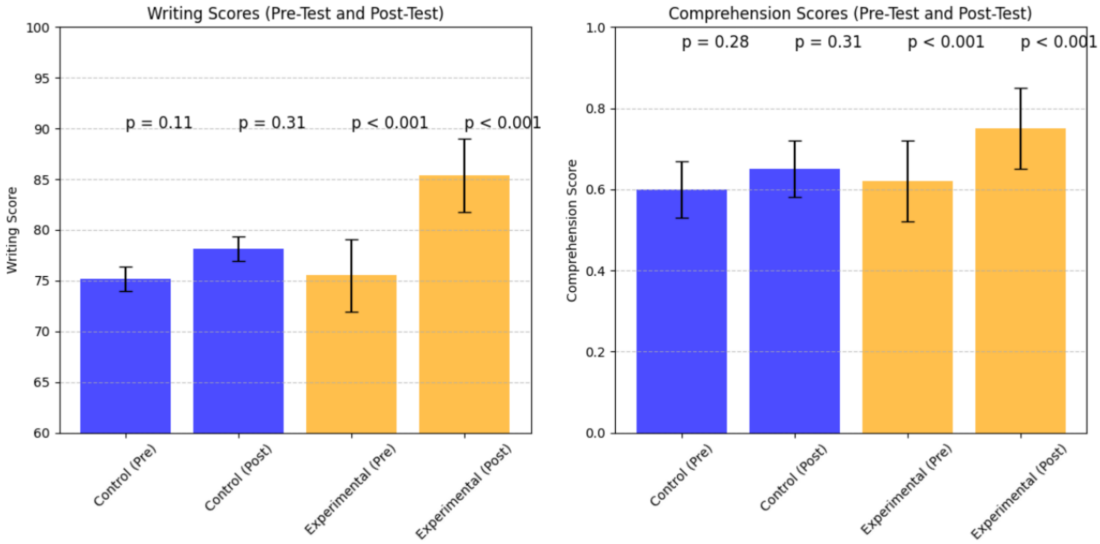

Figure 3. Comparison of writing and comprehension scores in control and experimental groups before and after the intervention.

Panel A: Writing Scores

In Panel A, the writing scores for both the control and experimental groups are shown across the pre-test and post-test conditions. The experimental group demonstrated a significant increase in writing scores from 75.5 ± 5.4 (pre-test) to 85.4 ± 4.1 (post-test), with a mean change of + 9.9 ± 3.6 points. This increase was statistically significant ($p < 0.001$), indicating a substantial improvement in writing performance as a result of the biomechanics-based intervention.

Conversely, the control group displayed a smaller, non-significant increase in writing scores, from 75.2 ± 5.1 at pre-test to 78.1 ± 4.7 at post-test, with a mean change of + 2.9 ± 1.2 points ($p = 0.11$). This modest improvement is within the range expected from typical exposure to English writing instruction and suggests that the traditional instructional methods used with the control group did not significantly impact writing performance.

The between-group comparison at post-test showed a significant difference in writing scores ($p < 0.001$), highlighting the effectiveness of the movement-integrated intervention in enhancing writing skills. This result supports the hypothesis that biomechanics-based physical movement can facilitate cognitive processes related to language tasks, leading to improved writing outcomes.

Panel B: Comprehension Scores

Panel B presents the comprehension scores on a 0–1 scale, illustrating similar trends to those observed in writing scores. The experimental group showed a statistically significant increase in comprehension scores from 0.62 ± 0.11 at pre-test to 0.75 ± 0.07 at post-test, with a mean change of + 0.13 ± 0.10 ($p < 0.001$). This improvement indicates that the biomechanics-based intervention positively impacted the participants' comprehension abilities, possibly by enhancing their focus and engagement through physical movement, which in turn may have facilitated cognitive processing and information retention.

In contrast, the control group demonstrated a minimal, non-significant increase in comprehension scores, from 0.60 ± 0.12 at pre-test to 0.65 ± 0.09 at post-test, with a mean change of + 0.05 ± 0.07 ($p = 0.28$). This result suggests that traditional instructional methods alone had a limited effect on comprehension skills over the study period.

The between-group comparison of post-test comprehension scores also indicated a statistically significant difference ($p < 0.001$), further supporting the efficacy of the movement-based intervention. This finding aligns with research in embodied cognition, which posits that integrating physical movement with cognitive tasks can enhance mental performance by activating multiple neural pathways involved in comprehension and retention.

Interpretation and Implications

The data in **Figure 3** provide robust evidence for the positive impact of a biomechanics-based physical movement intervention on both writing and comprehension outcomes among participants in the experimental group. The significant gains in the experimental group, as compared to the control group, indicate that incorporating physical movement into language tasks may facilitate better cognitive engagement and learning outcomes.

These findings contribute to the growing body of research suggesting that embodied learning strategies—where physical movement is integrated with cognitive activities—can enhance educational performance. By separating writing and comprehension scores into distinct panels, **Figure 3** provides a clear visualization of these improvements, free from the potential confusion of mixed scales. This separation of charts allows for a more precise interpretation of each variable, affirming the intervention's specific effects on distinct aspects of language learning.

In summary, **Figure 3** illustrates the differential impacts of traditional versus movement-integrated teaching methods on writing and comprehension. The biomechanics-based approach led to statistically significant improvements in both areas, suggesting that such interventions hold promise for enhancing cognitive and linguistic outcomes in educational settings. Future research may build on these findings by exploring the mechanisms underlying the observed improvements and assessing the intervention's applicability across diverse student populations and educational contexts.

3.4. Cultural considerations in student feedback

Several students noted that incorporating physical movement into academic tasks was a novel experience that differed from their traditional learning environment, which often emphasizes passive listening and individual work. Initially, some students felt hesitant to participate in physical activities due to cultural expectations regarding classroom behavior and modesty.

However, as the intervention progressed, many students reported that the physical movements helped them break out of their comfort zones, leading to increased confidence and willingness to engage. They found that the activities made the learning process more dynamic and helped them connect with the material on a deeper level.

3.5. Interpretation of results

3.5.1. Writing scores

The analysis of writing scores revealed significant differences between the experimental group and the control group following the intervention. The experimental group demonstrated a substantial increase in writing scores, with a pre-test mean of 75.5 ± 5.4 and a post-test mean of 85.4 ± 4.1, resulting in a mean change of + 9.9 ± 3.6 points. Statistical analysis using a paired t-test indicated that this increase was statistically significant ($p < 0.001$). In contrast, the control group showed a more modest increase in writing performance, from 75.2 ± 5.1 in the pre-test to 78.1 ± 4.7 in the post-test, yielding a mean change of + 2.9 ± 1.2 points. However, this increase did not reach statistical significance ($p = 0.11$).

The between-group comparison of post-test scores further emphasized the superior improvement in the experimental group. The experimental group outperformed the control group by a significant margin, with a difference in mean post-test writing scores of 7.3 points ($p < 0.001$), confirming the effectiveness of the biomechanics-based intervention in enhancing writing performance.

3.5.2. Comprehension scores

A similar pattern was observed in comprehension scores, where the experimental group showed significant improvement from 0.62 ± 0.11 (pre-test) to 0.75 ± 0.07 (post-test), resulting in a mean change of + 0.13 ± 0.10 ($p < 0.001$). This change represents a significant enhancement in comprehension ability following the biomechanics-based physical movement intervention.

In contrast, the control group exhibited a modest increase in comprehension scores, from 0.60 ± 0.12 at baseline to 0.65 ± 0.09 at post-test, with a mean change of + 0.05 ± 0.07. This increase was not statistically significant ($p = 0.28$), suggesting that the control group did not benefit to the same extent from the conventional instructional methods.

The between-group comparison of post-test comprehension scores further highlighted the superior improvement in the experimental group. The experimental group demonstrated a significantly greater increase in comprehension, with a mean difference of 0.10 between the groups ($p < 0.001$), underscoring the impact of the intervention on comprehension skills.

3.5.3. Baseline comparisons

Prior to the intervention, there were no significant differences between the experimental group and the control group for either writing or comprehension scores, confirming that the two groups were comparable at baseline. Specifically, the pre-test writing scores for the experimental group (75.5 ± 5.4) and the control group (75.2 ± 5.1) were not significantly different ($p = 0.93$). Similarly, the pre-test comprehension scores for both groups were nearly identical, with the experimental group scoring 0.62 ± 0.11 and the control group scoring 0.60 ± 0.12 ($p = 0.74$). These findings confirm that any differences observed at the post-test were attributable to the intervention rather than pre-existing disparities between the groups.

3.5.4. Summary of statistical findings

- The experimental group showed statistically significant improvements in both writing and comprehension scores ($p < 0.001$), while the control group showed only modest or non-significant changes.
- Between-group comparisons revealed that the experimental group outperformed the control group in both domains, with significant differences observed in both writing ($p < 0.001$) and comprehension ($p < 0.001$).
- The absence of significant differences at baseline supports the interpretation that the observed improvements in the experimental group were a result of the biomechanics-based physical movement intervention rather than baseline group differences.

4. Discussion

The study’s results provide strong evidence that incorporating physical movement into English writing instruction can significantly benefit Chinese undergraduate students. The notable improvements in writing and comprehension scores among the experimental group suggest that biomechanics-based physical activities enhance cognitive engagement, idea organization, and focus during writing tasks. These findings align with embodied cognition theory, which posits that physical experiences play an essential role in cognitive processes. Structured physical movements appear to activate multiple neural pathways, facilitating more effective language processing and memory retention, which are key for writing fluency and coherence [1,2].

4.1. Cultural interpretation of findings

The significant improvements in the experimental group can be understood within the context of Chinese educational culture, which traditionally emphasizes rote memorization, teacher-centered instruction, and examination performance. Such an approach often positions students as passive recipients of knowledge, with limited opportunities for interactive or experiential learning [3]. The introduction of physical movement in the classroom represents a departure from these norms. Initially, students may experience discomfort or hesitation due to cultural expectations of modesty and a respect for authority figures, which can discourage unconventional activities in academic settings [4,5].

However, the positive outcomes observed in this study suggest that students can derive substantial benefits from active, embodied learning experiences. Physical movements likely helped students internalize language structures and organize thoughts more effectively. By engaging both the mind and body, students may access diverse cognitive pathways that enhance memory retention and idea generation. This impact is particularly relevant for Chinese students, who often struggle with English writing fluency and coherence due to structural and cognitive differences between Chinese and English [6].

4.2. Implications for educational practices in China

This study's findings have significant implications for English language teaching practices in China. Integrating biomechanics-based physical movements into instructional practices can address some limitations inherent in traditional methods, such as the overemphasis on memorization and the resulting lack of student engagement. By adopting a more holistic approach that incorporates physical activity, educators can foster a more interactive, student-centered learning environment. This approach develops not only language skills but also confidence, creativity, and critical thinking abilities, aligning with China's recent educational reforms aimed at cultivating well-rounded individuals [7].

Cultural considerations are also critical when implementing new teaching strategies. Teachers should be mindful of students' initial reservations and provide supportive guidance to help them adapt to movement-based learning. By explaining the purpose and benefits of these physical activities, teachers can help alleviate student concerns and promote active participation, making the learning process more engaging and cognitively enriching [8].

4.3. Addressing cultural challenges

While this study underscores the effectiveness of movement-based interventions, it also highlights potential cultural challenges. Some students may feel self-conscious or perceive physical activities as unsuitable within an academic setting. Teachers can implement strategies to ease students into these activities, helping to address these cultural barriers:

- Introduce Activities Gradually: Begin with simple, low-intensity movements and gradually incorporate more complex activities as students gain comfort.
- Create a Supportive Environment: Cultivate a classroom culture where experimentation and active participation are valued.
- Provide Clear Explanations: Explain the cognitive benefits of physical movement to help students understand the purpose behind these activities.
- Respect Individual Differences: Allow students to participate at their own comfort level, offering alternatives if necessary.

By considering cultural norms and individual student needs, teachers can integrate movement-based strategies in ways that are both culturally appropriate and maximally effective [9].

4.4. Comparison with existing literature

This study contributes to the growing body of research on embodied cognition and its application in language learning. Previous studies have shown that physical movement can enhance memory and learning outcomes across various subjects, underscoring the value of active engagement in the learning process [10]. However, limited research has explored how these principles apply specifically to English writing instruction for Chinese students. The study's findings support the notion that physical engagement can facilitate cognitive processes involved in writing, including idea generation, organization, and language retention. These results align with embodied cognition theories, which suggest that cognitive functions are deeply connected to physical experiences, offering a multi-modal approach to language learning [11].

Furthermore, this study provides insights into the influence of cultural factors on educational interventions. Despite traditional practices, Chinese students demonstrated adaptability and benefited from teaching methods that encourage active participation. This adaptability indicates that Chinese educational contexts could incorporate more interactive approaches, positioning embodied learning as a valuable complement to traditional instruction [3].

4.5. Neural pathways

The findings from this study suggest that incorporating biomechanics-based physical movement into language learning tasks, such as writing and comprehension exercises, can enhance cognitive engagement and lead to improved performance. These improvements may be partially explained by theories of embodied cognition, which posit that physical movement can support cognitive processes by engaging both the motor and cognitive systems. While direct evidence of neural pathway activation was not collected in this study, existing literature provides some insights into possible mechanisms that could underlie the observed benefits.

Research in cognitive neuroscience has demonstrated that engaging the body in movement can stimulate brain regions associated with attention, memory, and executive function, areas that are critical for complex cognitive tasks like writing and comprehension [28]. Studies using imaging techniques, such as fMRI and EEG, have shown that motor activities can activate regions beyond the motor cortex, including the prefrontal cortex and parietal cortex—regions involved in cognitive control and spatial processing, which are essential for tasks requiring sustained attention and spatial organization [29]. The activation of these regions could potentially enhance task performance by facilitating information processing and mental organization, which are fundamental to effective language use.

In this study, the significant improvement in writing and comprehension scores in the experimental group, compared to the control group, aligns with the hypothesis that physical movement may serve as a tool to support cognitive functions related to language tasks. Specifically, the use of biomechanics-based interventions might encourage a form of sensorimotor grounding, wherein the body's engagement in movement assists in anchoring abstract concepts to concrete, embodied experiences. This anchoring could help students organize their thoughts more effectively and maintain focus, leading to improved outcomes. However, while the improvements observed in this study are consistent with findings from research on embodied cognition, the exact neural mechanisms remain speculative.

Future research could employ neuroimaging techniques to examine whether and how specific brain regions are activated during movement-integrated language tasks. Investigating the involvement of neural networks, particularly those involved in attention modulation, working memory, and cognitive control, could provide a clearer understanding of how biomechanics-based interventions influence cognitive processes. Additionally, understanding the role of interoceptive and proprioceptive feedback—internal bodily cues that arise during physical movement—might offer further insights into the potential neural pathways that support language learning in an embodied context.

In conclusion, while this study supports the potential cognitive benefits of incorporating movement into language learning tasks, claims regarding the activation of "multiple neural pathways" should be interpreted with caution. The observed improvements in performance likely result from a combination of physical engagement and cognitive processing, which may activate interconnected neural networks. However, without direct neural data, the precise mechanisms remain speculative. These findings underscore the importance of further interdisciplinary research to clarify the relationship between physical movement, cognitive enhancement, and neural activity in the context of educational interventions.

4.6. Limitations and future research directions

While the study yielded positive results, several limitations should be acknowledged:

- Sample Size and Diversity: This study was conducted with a relatively small group of students from a single university. Future research should involve a larger and more diverse sample to improve the generalizability of the findings.
- Short-Term Intervention: The study spanned eight weeks. Longitudinal studies are needed to examine the long-term effects of movement-based interventions on writing skills, assessing if improvements persist beyond the intervention period.
- Type of Physical Movements: The interventions focused on specific hand and arm movements. Expanding this to include a broader range of physical activities, such as full-body movements, could provide additional insights into the benefits of biomechanics-based learning.
- Cultural Adaptation: Future research should explore culturally adapted movement-based activities that align with Chinese students' preferences and comfort levels, optimizing engagement and effectiveness within specific cultural contexts.

Further research could also examine the neural mechanisms underlying these improvements, perhaps using neuroimaging techniques to investigate how physical movement influences brain activity related to language processing and cognitive engagement. Such research would deepen our understanding of the interaction between physical and cognitive processes in language learning, helping refine movement-based strategies to maximize their educational benefits [12].

4.7. Practical applications and recommendations

Educators teaching English to Chinese college students can consider incorporating biomechanics-based strategies into their instruction. Specific recommendations include:

- Pre-Writing Exercises: Implement brief physical activities to cognitively prepare students for writing tasks, enhancing focus and mental readiness.
- Gesture-Based Prompts: Use specific gestures to represent writing concepts, aiding in idea organization and memory retention, and facilitating smoother transitions between different stages of the writing process.
- Active Learning Environments: Encourage movement and physical engagement within the classroom to foster sustained attention, participation, and enhanced focus.

These practices are versatile and can be adapted to various teaching contexts, including large classes and remote learning platforms. By integrating biomechanics-based physical activities into language instruction, educators can foster a more interactive and supportive learning environment, encouraging students to develop both linguistic proficiency and essential cognitive skills [6,13].

These quantitative findings are further explored in the Discussion section, where we interpret the implications of the results in relation to existing literature on embodied cognition and language learning.

5. Conclusion

The results from this study show significant improvements in writing and comprehension in the experimental group. In this section, we interpret these findings within the context of embodied cognition theory and explore their implications for language pedagogy.

This study explored the impact of integrating biomechanics-based physical movements into English writing instruction for Chinese undergraduate students. The findings indicate that such interventions can significantly improve writing quality and comprehension, suggesting that physical movement enhances cognitive processes essential for effective language learning.

From a cultural perspective, the study highlights the potential of innovative teaching methods to enhance student engagement and learning outcomes in a context traditionally characterized by passive learning and teacher-centered instruction. By considering cultural characteristics and addressing potential challenges, educators can successfully implement movement-based strategies that enrich the learning experience.

The implications for English language education in China are significant. Incorporating physical movement into writing instruction can:

- Enhance Student Engagement: Active participation can make learning more enjoyable and increase motivation.
- Improve Cognitive Function: Physical movements can aid in memory retention and idea organization.
- Develop Holistic Skills: Beyond language proficiency, students can develop confidence, creativity, and critical thinking abilities.

To maximize the effectiveness of these interventions, educators should:

- Be Culturally Sensitive: Understand and address cultural norms and student perceptions.
- Provide Support and Encouragement: Help students adapt to new learning modalities.
- Customize Activities: Tailor physical movements to align with instructional goals and student needs.

In conclusion, integrating biomechanics-based physical movements into English writing instruction offers a promising approach to enhancing language education in China. By bridging cognitive and physical engagement, educators can support students in developing stronger writing skills and greater confidence in their language abilities. Future research should continue to explore this approach, considering cultural factors and seeking to optimize its effectiveness within the Chinese educational context.

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