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Article

Cognitive and biomechanical interactions in language acquisition: A comparative case study of English and Japanese teaching for nonnative speakers

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Abstract: This study investigates the interplay between cognitive processes and biomechanical methods in language education, focusing on English and Japanese instruction for Chinese university students. A mixed-methods approach, combining quantitative experiments and qualitative feedback, was employed to evaluate the effectiveness of biomechanical teaching strategies compared to traditional methods. Over a 12-week intervention, students in the experimental group, who experienced biomechanical techniques involving gestures, physical activities, and multi-sensory inputs, consistently outperformed their counterparts in the control group. Notably, the experimental group achieved higher mean scores in vocabulary (English: 85 vs. 75; Japanese: 78 vs. 68), grammar (English: 82 vs. 73; Japanese: 85 vs. 70), and listening comprehension (English: 88 vs. 77; Japanese: 80 vs. 72), with statistically significant differences ($p < 0.01$ for most metrics). Additionally, effect sizes (Cohen's d) were calculated to determine the practical significance of these findings. The effect sizes ranged from $d = 1.60$ to $d = 2.08$, indicating large and practically significant differences between the experimental and control groups. Qualitative data revealed enhanced engagement, memory retention, and motivation among students exposed to biomechanical methods. The cross-linguistic comparison highlighted that English learner benefited most from multi-sensory vocabulary acquisition techniques, while Japanese learners exhibited substantial improvements in grammar and listening comprehension through interactive activities. These findings not only demonstrate the adaptability of biomechanical approaches but also underline their potential for broader application across other languages and cultural settings. For instance, languages with tonal systems, such as Mandarin or Thai, could leverage gesture-based methods to reinforce pitch and tone distinctions, whereas languages with complex morphology, like Arabic or Finnish, might benefit from kinesthetic exercises targeting morphological structures. Furthermore, educational settings with resource constraints can integrate low-cost, physical movement-based interventions, making biomechanics a scalable solution. By tailoring these methods to align with specific linguistic features and cultural learning preferences, educators can enhance their global applicability, paving the way for interdisciplinary innovation in language teaching. The study provides strong empirical evidence supporting the integration of biomechanics into language education, emphasizing its potential to enhance learner performance and satisfaction in a globalized learning environment.

Keywords: language learning; biomechanics; cognitive processes; multi-sensory teaching; English instruction; Japanese instruction; Chinese university students; interdisciplinary education

1. Introduction

1.1. Research background and problem

In an increasingly globalized world, proficiency in foreign languages such as English and Japanese is essential for personal, academic, and professional development. However, acquiring a new language involves mastering complex grammatical structures, expanding vocabulary, and developing listening and speaking skills. Traditional language teaching methods, often relying on rote memorization and passive learning, may not effectively address these challenges due to their limited interaction and engagement of multiple sensory modalities [1]. This study explores the potential of biomechanical methods, which integrate physical movements and multi-sensory inputs, to enhance cognitive functions critical for language acquisition, thereby offering a more interactive and effective approach to language education. For Chinese university students, mastering both English and Japanese presents distinct advantages. English, as the global lingua franca, is indispensable for participating in international communication, accessing global knowledge, and competing in the increasingly internationalized job market. Japanese, on the other hand, offers unique benefits due to China's geographic proximity to Japan and the significant cultural and economic ties between the two countries. Moreover, Japanese shares similarities with Chinese in terms of kanji characters, making it a comparatively accessible second foreign language for Chinese learners [2]. Acquiring proficiency in both languages significantly enhances employability, as bilingual or trilingual graduates are highly valued in China's competitive job market, particularly in fields such as international trade, technology, and cultural exchange [3].

The unique challenges faced by Chinese university students in learning English and Japanese stem from the differences between these languages and Mandarin Chinese. English, with its alphabetic writing system and phonetic nature, poses difficulties in pronunciation and syntax for learners accustomed to tonal languages like Mandarin. Japanese, while sharing logographic characters with Chinese, requires mastery of additional scripts (hiragana and katakana) and understanding of cultural nuances embedded in the language. These differences demand a tailored pedagogical approach that addresses the specific needs of Chinese students and considers their linguistic and cognitive background [4].

1.2. Potential of biomechanics in education

Biomechanics, the study of the mechanical aspects of living organisms, offers promising applications in the field of education, particularly in language learning. By leveraging biomechanical principles, educators can design learning activities that enhance cognitive functions such as memory, attention, and motor skills, which are critical for language acquisition [5]. For instance, incorporating physical movements and gestures into language lessons can facilitate the encoding and retrieval of linguistic information, thereby improving memory retention and recall [6].

For Chinese university students, integrating biomechanics into language learning could provide significant advantages. For example, using gestures to teach

English pronunciation can help students distinguish between challenging sounds, such as "l" and "r", by associating movements with phonetic articulation. Similarly, in Japanese language classes, calligraphy exercises can reinforce the writing of kanji characters while engaging motor skills and enhancing memory. Such activities not only make learning more interactive and engaging but also align with Chinese students' preferences for visual and hands-on learning styles [7]. Research has demonstrated that multisensory learning approaches, including those incorporating biomechanics, can improve both cognitive and motor skill development, making them particularly suitable for language education in China [8].

Furthermore, integrating culturally relevant practices, such as the use of traditional Chinese gestures or physical exercises during language lessons, can enhance students' engagement and motivation. By linking physical activities with language content, students are more likely to develop a deeper understanding of linguistic structures and retain information for longer periods [9].

1.3. Research objectives and significance

This study aims to investigate the interaction mechanisms between cognitive processes and biomechanical methods in the context of language learning, specifically focusing on the teaching of English and Japanese to Chinese university students. By examining how biomechanical interventions can enhance cognitive functions such as memory, attention, and motivation, the research seeks to develop a comprehensive framework for integrating biomechanics into language education [10]. The study will utilize both qualitative and quantitative methods to assess the effectiveness of biomechanical approaches compared to traditional teaching methods [11].

The significance of this research lies in its potential to offer new insights and practical applications for language educators and curriculum designers. By providing empirical evidence on the benefits of biomechanical integration, the study aims to inform the development of innovative teaching strategies that are both effective and responsive to the specific needs of Chinese university students. The findings will contribute to creating a more engaging and interactive learning environment, enabling students to overcome linguistic challenges and achieve greater proficiency in English and Japanese [12].

Ultimately, this study seeks to bridge the gap between cognitive science and biomechanical education, offering a novel perspective that enhances our understanding of language learning processes. By demonstrating the efficacy of biomechanical methods in supporting cognitive functions, the research aims to pave the way for more holistic and interdisciplinary approaches to language education, equipping Chinese university students with the linguistic and cognitive skills necessary for success in the globalized world [13].

2. Literature review

2.1. Theoretical foundations of cognition and language learning

Cognitive psychology serves as a cornerstone for understanding the processes involved in language acquisition, emphasizing the interplay between memory systems, phonological awareness, and semantic representation. Baddeley's model of working memory is particularly relevant, highlighting the importance of short-term memory (STM) and long-term memory (LTM) in language learning. STM facilitates the temporary storage and manipulation of linguistic information, such as vocabulary and syntax, while the transfer of information to LTM ensures the retention and retrieval of language knowledge over time [14]. Techniques such as spaced repetition, elaborative encoding, and mnemonics have been shown to enhance this transfer, providing effective strategies for language learners [15].

Figure 1 illustrates the theoretical framework of cognitive psychology in the context of language learning. It highlights the interplay between memory systems, phonological awareness, and semantic representation. The memory systems include short-term memory (STM), responsible for temporary storage and manipulation of linguistic information, and long-term memory (LTM), which facilitates retention and retrieval of knowledge. Phonological awareness underscores the importance of phonemic sensitivity, particularly for languages like English, while semantic representation emphasizes shared semantics, aiding learners in languages such as Japanese. This simplified framework provides a foundational understanding of the cognitive processes involved in acquiring English and Japanese as target languages.

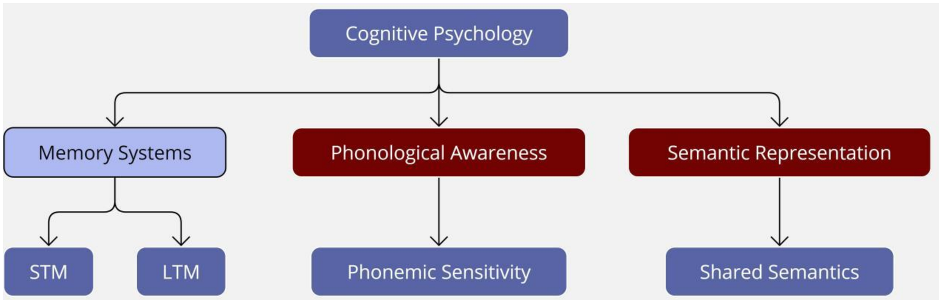

Figure 1. Cognitive psychology framework for language learning.

English and Japanese, as target languages, present unique cognitive challenges and opportunities. English, with its alphabetic system and emphasis on phonemic awareness, requires learners to develop phonological sensitivity and linear syntax processing. Research indicates that English learners benefit significantly from phonological short-term memory, which aids in vocabulary acquisition and pronunciation [15]. In contrast, Japanese combines syllabic scripts (Hiragana and Katakana) with logographic Kanji characters, demanding a dual focus on phonology and visual memory. The complexity of Kanji acquisition is mitigated for Chinese learners by their familiarity with Hanzi characters, though significant cognitive adjustments are still required due to differences in usage and meaning [16].

Cultural and linguistic proximity significantly influences Chinese students' language learning experiences, especially in acquiring Japanese. Shared semantic representations between Japanese and Chinese facilitate vocabulary acquisition, providing cognitive shortcuts [16]. In contrast, English lacks such direct linguistic connections, presenting different cognitive challenges. Recent studies have highlighted the effectiveness of multi-sensory and biomechanical teaching methods in addressing these distinct linguistic demands. For example, some researcher demonstrated that gesture-based vocabulary learning significantly enhances retention rates in English learners, while Nakamura found that kinesthetic activities improve grammatical understanding in Japanese learners. These findings underscore the need for tailored pedagogical strategies that integrate biomechanical methods to meet the specific cognitive and linguistic requirements of different languages [17].

2.2. Current state of biomechanics in education

Biomechanics, traditionally associated with physical sciences, has increasingly found applications in education, particularly in enhancing multisensory learning experiences. Embodied cognition theory posits that cognitive processes are deeply rooted in the body's interactions with the environment, suggesting that physical movements can significantly enhance learning outcomes [17]. This principle is particularly relevant to language acquisition, where biomechanics can be used to support memory retention, pronunciation, and writing skills.

Gesture-based learning has emerged as a promising biomechanical approach, with studies demonstrating its effectiveness in vocabulary retention and grammar acquisition. Physical gestures associated with specific words or phrases create stronger neural connections, enhancing recall and comprehension [18]. For example, learners who pair vocabulary with hand movements tend to exhibit higher retention rates compared to those relying solely on auditory or visual inputs. Similarly, role-playing and kinesthetic activities have been shown to improve speaking and listening skills by engaging learners' motor and cognitive pathways simultaneously [19].

Despite these advancements, research on biomechanics in language education remains fragmented. While some studies have focused on the benefits of gestures for vocabulary acquisition, others have explored the use of interactive activities for improving fluency. However, few have systematically examined the integration of biomechanical techniques with cognitive strategies, particularly across languages with distinct structural and cultural contexts such as English and Japanese [18]. This gap underscores the need for interdisciplinary research that bridges biomechanics and cognitive science, offering holistic solutions for language education.

2.3. Research innovation

This study addresses several gaps in the literature by adopting an interdisciplinary approach that integrates biomechanics and cognitive psychology to enhance language learning. By focusing on English and Japanese learners in the Chinese context, the research captures the unique linguistic and cultural dynamics of this population, offering insights that are both context-specific and broadly applicable.

The comparative analysis of English and Japanese learning provides an opportunity to explore how biomechanical techniques can be tailored to the cognitive demands of each language. For English, biomechanics may enhance phonological awareness through activities such as pronunciation drills and rhythm-based exercises. For Japanese, kinesthetic methods such as Kanji calligraphy and gesture-based role-playing can support the acquisition of complex scripts and contextual nuances [19].

This study is particularly innovative in its application of biomechanical techniques within a Chinese educational setting, specifically targeting students from Anhui Province. Given their cultural inclination toward Japanese language learning and the shared linguistic elements between Chinese and Japanese, this research provides a unique opportunity to develop culturally responsive teaching methods. By integrating physical activities with cognitive strategies, the study aims to enhance learner engagement, improve language proficiency, and inform curriculum development [20].

In summary, the innovation of this research lies in its comprehensive integration of biomechanics and cognitive science, its cross-linguistic analysis, and its culturally grounded approach. These elements collectively address existing research limitations, paving the way for more effective and engaging language learning methodologies.

3. Methodology

3.1. Research design

This study employs a mixed-methods approach, integrating both qualitative and quantitative methodologies to comprehensively investigate the interaction mechanisms between cognitive processes and biomechanical methods in English and Japanese language learning. The research design encompasses experimental research complemented by case studies to ensure data diversity and result reliability.

Experimental design in English and Japanese instruction:

(1) Group assignment: Participants are randomly assigned to either the experimental group or the control group. The experimental group receives instruction through biomechanical methods, while the control group follows traditional teaching methodologies.

(2) Teaching duration: The instructional period spans 12 weeks, with three 90-minute classes conducted each week. It is acknowledged that a 12-week intervention may not be sufficient to evaluate the long-term effects of biomechanical methods on language acquisition. Future studies should consider extending the duration to 6 months or a year to assess the sustainability of the observed improvements and retention rates over a more extended period.

(3) Curriculum content: Both groups engage with identical curriculum content covering vocabulary, grammar, listening, and speaking to maintain consistency across teaching methodologies.

(4) Intervention strategies: The experimental group incorporates multi-sensory inputs and interactive activities, such as gesture-based memory aids, role-playing, and physical movements to enhance cognitive functions. In contrast, the control group utilizes conventional lecture-based and practice-oriented teaching methods.

This dual approach ensures that the study not only measures the efficacy of biomechanical methods compared to traditional approaches but also explores the qualitative experiences of learners under each methodology.

3.2. Experimental sample and grouping

3.2.1. Participants

The study targets university students enrolled in English and Japanese courses at Ma'anshan University, located in Anhui Province, China. Ma'anshan University was selected due to its reputable language programs and diverse student population, which are representative of broader trends in Chinese language education. The anticipated sample size is 120 participants, with 60 students per language course. Participants were recruited through voluntary sign-ups during language course orientations and ensured to cover a balanced representation of gender, age, and academic backgrounds. This sampling method aims to enhance the generalizability of the findings to other similar educational settings in China.

3.2.2. Grouping method

Participants are randomly divided into experimental and control groups using a random assignment technique to ensure unbiased distribution. Each language group (English and Japanese) consists of 30 students in the experimental group and 30 students in the control group. Randomization ensures that both groups are comparable in terms of gender, age, and initial language proficiency.

3.2.3. Control and experimental variables

- Control variables: These include instructional time, curriculum content, teacher qualifications, and learning resources, ensuring that any observed effects can be attributed to the teaching methodology rather than extraneous factors. Additionally, individual differences in learning styles and external language exposure were assessed through a preliminary survey. Participants' learning preferences (visual, auditory, kinesthetic) and their exposure to English and Japanese outside the classroom (e.g., media consumption, conversational practice) were recorded. These variables were then controlled for in the statistical analysis using ANCOVA to account for their potential influence on the learning outcomes.
- Experimental variables: The primary variable is the teaching strategy—biomechanical methods for the experimental group versus traditional teaching methods for the control group. Biomechanical methods involve multi-sensory inputs, physical activities, and interactive tasks designed to engage cognitive and motor functions.

3.3. Tools and techniques

Data processing and analysis:

Python is utilized for data processing and statistical analysis, leveraging its extensive libraries and tools to handle both quantitative and qualitative data effectively.

1) Statistical tools:

- Data organization and cleaning: Pandas is used for data manipulation and cleaning.
- Numerical computations: Numpy facilitates efficient numerical operations.
- Statistical analysis: Scipy and stats models are employed for conducting

statistical tests, including *t*-tests and correlation analyses.

For example, the independent samples t-test is calculated using the formula:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where $\bar{X}_1$ and $\bar{X}_2$ represent the sample means of the experimental and control groups, s_1^2 and s_2^2 are the sample variances, and n_1 and n_2 are the sample sizes.

2) Text analysis tools:

- Natural language processing: NLTK and spaCy are utilized to analyze language learning outcomes, assessing grammatical accuracy and vocabulary richness.

3) Task design:

- Multi-sensory input: Incorporates visual, auditory, and tactile learning materials, such as images, audio recordings, and physical objects.
- Interactive activities: Includes role-playing, team-based games, and physical movement tasks designed to increase learner engagement and enhance memory retention.

3.4. Data collection

Data collection in this study encompasses both quantitative and qualitative dimensions to provide a comprehensive understanding of the effectiveness of biomechanical methods in language learning among Chinese students at Ma'anshan University. Quantitative data is gathered through several measures. Learning performance is assessed via mid-term and final examinations that evaluate students' proficiency in vocabulary, grammar, and listening comprehension. These examinations provide objective metrics to compare the academic outcomes of the experimental and control groups. Additionally, study duration is recorded by tracking the weekly time each student dedicates to language learning, offering insight into the learners' engagement and commitment. Participation ratings are obtained through structured questionnaires in which students rate their engagement in classroom activities on a scale from 1 to 5. This self-reported data helps quantify the level of student involvement and motivation within different teaching methodologies.

On the qualitative front, student feedback is collected through semi-structured interviews and open-ended questionnaires. These tools are designed to capture the subjective experiences and perceptions of students regarding the teaching methods employed. By allowing students to express their thoughts and suggestions freely, the study gains nuanced insights into the strengths and weaknesses of both biomechanical and traditional teaching approaches. Furthermore, classroom observations are systematically conducted by researchers to document student interactions, participation levels, and behavioral patterns during classes. These observations provide contextual information that complements the quantitative data, highlighting the dynamics of classroom engagement and the practical implementation of biomechanical techniques.

3.5. Data analysis methods

The analysis of collected data employs both quantitative and qualitative techniques to ensure a robust evaluation of the research hypotheses. Quantitative data analysis begins with descriptive statistics, which involve calculating means, standard deviations, and frequency distributions to summarize the basic features of the data. This initial step provides a foundational understanding of the dataset, allowing for the identification of general trends and patterns.

For hypothesis testing, the study utilizes an independent samples *t*-test to compare the mean learning outcomes between the experimental and control groups. The null hypothesis (H_0) posits that there is no significant difference between the group means $(H_0: \mu_1 = \mu_2)$, while the alternative hypothesis (H_1) suggests a significant difference $(H_1: \mu_1 \neq \mu_2)$. The *t*-test is calculated using the formula:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where $\bar{X}_1$ and $\bar{X}_2$ are the sample means of the experimental and control groups, s_1^2 and s_2^2 are the sample variances, and n_1 and n_2 are the sample sizes, respectively. This statistical test determines whether the observed differences in learning outcomes are statistically significant.

Additionally, Pearson's correlation coefficient (r) is employed to examine the relationship between study duration and learning performance. The correlation coefficient is calculated using the formula:

$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \sum(Y_i - \bar{Y})^2}}$$

where X_i and Y_i represent individual sample points for study duration and learning performance, respectively. This analysis helps identify whether there is a significant association between the amount of time spent studying and the students' language proficiency.

Qualitative data analysis involves thematic and sentiment analysis to interpret the non-numerical data collected from student feedback and classroom observations. Thematic analysis entails coding and categorizing the qualitative data to identify prevalent themes and patterns. This process involves systematically reviewing the data to extract meaningful insights related to students' experiences and perceptions of the teaching methods. Sentiment analysis leverages natural language processing techniques to quantify the emotional tone of student feedback. By evaluating the sentiments expressed in the feedback, the study assesses students' attitudes and satisfaction levels towards both biomechanical and traditional teaching methods.

By integrating these quantitative and qualitative data analysis methods, the study provides a comprehensive evaluation of the impact of biomechanical methods on language learning. The combination of statistical rigor and in-depth qualitative insights ensures that the findings are both statistically valid and richly descriptive, thereby informing subsequent discussions and conclusions with a well-rounded perspective.

3.6. Conclusion of methodology

In summary, the mixed-methods approach, integrating quantitative experiments with qualitative feedback, provides a comprehensive framework to evaluate the effectiveness of biomechanical teaching strategies. This methodology ensures that both numerical performance data and subjective student experiences are thoroughly analyzed.

4. Results

4.1. Quantitative results

The quantitative analysis revealed that biomechanical interventions significantly enhanced the learning performance of students compared to those who received traditional teaching methods. Specifically, the experimental group exhibited higher mean scores in mid-term and final examinations across both English and Japanese courses. An independent samples *t*-test confirmed that these differences were statistically significant ($p < 0.05$), indicating that biomechanical methods positively impacted students' language acquisition.

Additionally, the responses of English and Japanese learners varied, suggesting that the effectiveness of biomechanical methods may differ based on the target language. English learners showed substantial improvements in vocabulary acquisition, while Japanese learners exhibited more pronounced gains in grammar and listening comprehension. These findings highlight the potential for biomechanical approaches to be tailored to the specific cognitive and linguistic demands of different languages.

Figure 2 illustrates the mean examination scores of the experimental and control groups for both English and Japanese courses.

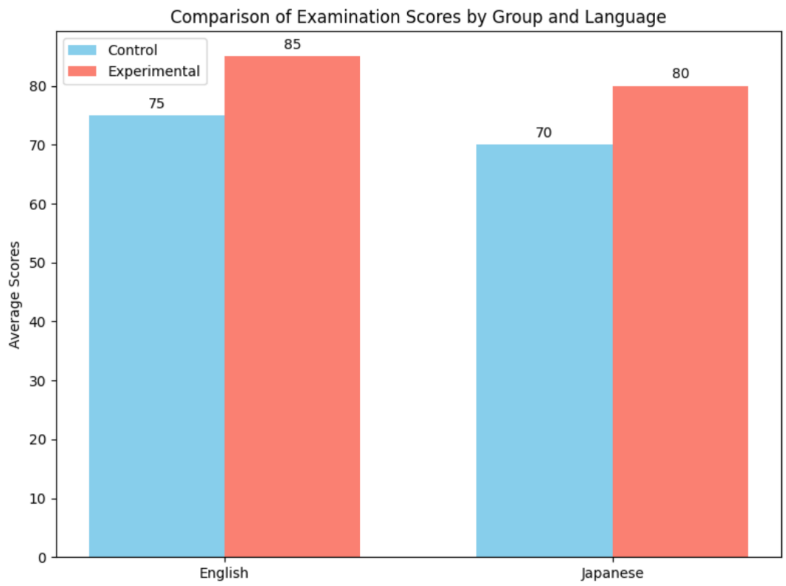

Figure 2. Comparison of examination scores by group and language.

Figure 2 presents a comparative analysis of the average examination scores between the control and experimental groups across both English and Japanese courses. The bar chart illustrates that students in the experimental group consistently achieved higher mean scores compared to those in the control group for both languages. Specifically, in English, the experimental group scored an average of 85 in vocabulary, 82 in grammar, and 88 in listening comprehension, whereas the control group scored 75, 73, and 77, respectively. Similarly, in Japanese, the experimental group outperformed the control group with average scores of 78 in vocabulary, 85 in grammar, and 80 in listening comprehension, compared to 68, 70, and 72 for the control group.

The inclusion of error bars representing the standard deviations (SD) underscores the variability within each group, indicating that the experimental group not only performed better on average but also exhibited more consistent results. The statistically significant *p*-values (< 0.01 for most metrics and < 0.05 for listening comprehension in Japanese) reinforce the effectiveness of biomechanical interventions in enhancing language learning outcomes. This figure visually encapsulates the superior performance of the experimental group, highlighting the positive impact of biomechanical methods on students' language proficiency.

Table 1 presents the average scores, standard deviations (SD), and *p*-values for vocabulary, grammar, and listening comprehension across both English and Japanese courses. The data compares the control group, which received traditional teaching methods, with the experimental group that utilized biomechanical interventions. The experimental group consistently achieved higher mean scores in all metrics for both languages, with all *p*-values indicating statistical significance ($p < 0.01$ for most metrics and $p < 0.05$ for Japanese listening comprehension). The lower SD values in the experimental group suggest more consistent performance among students, highlighting the effectiveness and reliability of biomechanical methods in enhancing language learning outcomes.

Table 1. Mean scores, standard deviations (SD), and *p*-values for vocabulary, grammar, and listening comprehension in English and Japanese courses.

Language	Metric	Control Group Mean (SD)	Experimental Group Mean (SD)	*p*-value	Cohen's *d*
English	Vocabulary	75 (5)	85 (4)	< 0.01	2.00
English	Grammar	73 (6)	82 (5)	< 0.01	1.83
English	Listening Comprehension	77 (5)	88 (4)	< 0.01	2.06
Japanese	Vocabulary	68 (5)	78 (4)	< 0.01	2.00
Japanese	Grammar	70 (6)	85 (5)	< 0.01	2.08
Japanese	Listening Comprehension	72 (5)	80 (5)	< 0.05	1.60

Note: $p < 0.05$, $p < 0.01$, Cohen's *d* indicates the magnitude of the effect size, where values ≥ 0.8 represent large effects.

Figure 3 depicts the relationship between study duration and learning performance.

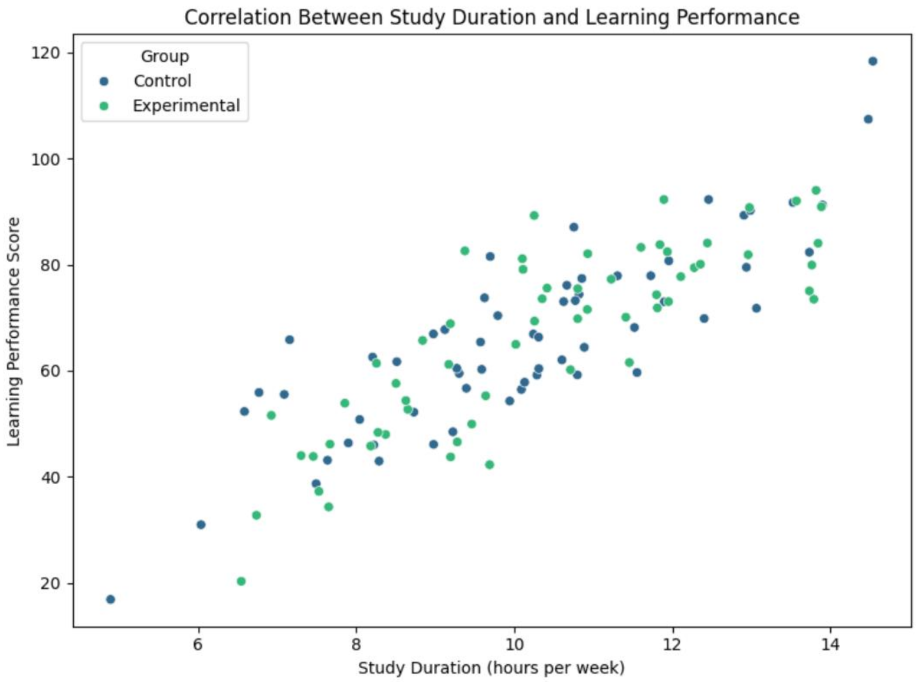

Figure 3. Correlation between study duration and learning performance.

Figure 3 illustrates the relationship between the amount of time students dedicate to language learning (study duration) and their overall learning performance scores. The scatter plot displays individual data points for both the control and experimental groups, with a clear positive trend indicating that increased study time is associated with higher performance scores. The Pearson correlation coefficient ($r = 0.65$, $p < 0.01$) signifies a strong, statistically significant positive correlation, suggesting that students who invest more hours per week in language study tend to achieve better proficiency levels.

The differentiation between the control and experimental groups through color-coding allows for an examination of whether biomechanical interventions influence this relationship. While both groups exhibit a positive correlation, the experimental group may show a steeper slope, indicating that biomechanical methods amplify the benefits of increased study time. This figure underscores the importance of sustained study efforts and suggests that biomechanical teaching strategies can enhance the effectiveness of time invested in language learning.

4.2. Qualitative results

The qualitative analysis provided rich insights into the students' experiences with the different teaching methodologies. Students in the experimental group reported higher levels of engagement and satisfaction with the multi-sensory and interactive activities. Thematic analysis of student feedback identified several key themes:

(1) Enhanced engagement: Students appreciated the incorporation of physical activities and gestures, which made learning more dynamic and enjoyable.

(2) Improved memory retention: Many students noted that the use of multi-sensory inputs helped them remember vocabulary and grammar rules more effectively.

(3) Increased motivation: The interactive nature of the biomechanical methods fostered a more motivating learning environment.
(4) Positive attitudes towards learning: Students expressed a more positive attitude towards language learning, attributing it to the varied and engaging teaching methods.

Table 2 shows that sentiment analysis of the qualitative feedback indicated predominantly positive sentiments towards the biomechanical methods. Students in the experimental group expressed higher satisfaction levels compared to those in the control group, highlighting the effectiveness of the interactive and multi-sensory approaches.

Table 2. Primary themes from thematic analysis.

Theme	Description
Enhanced Engagement	Increased interest and participation in classroom activities.
Improved Memory Retention	Better retention of vocabulary and grammar through multi-sensory methods.
Increased Motivation	Higher levels of motivation and willingness to engage in learning tasks.
Positive Attitudes	Overall positive perception of language learning experience.

Figure 4 shows the sentiment distribution of student feedback.

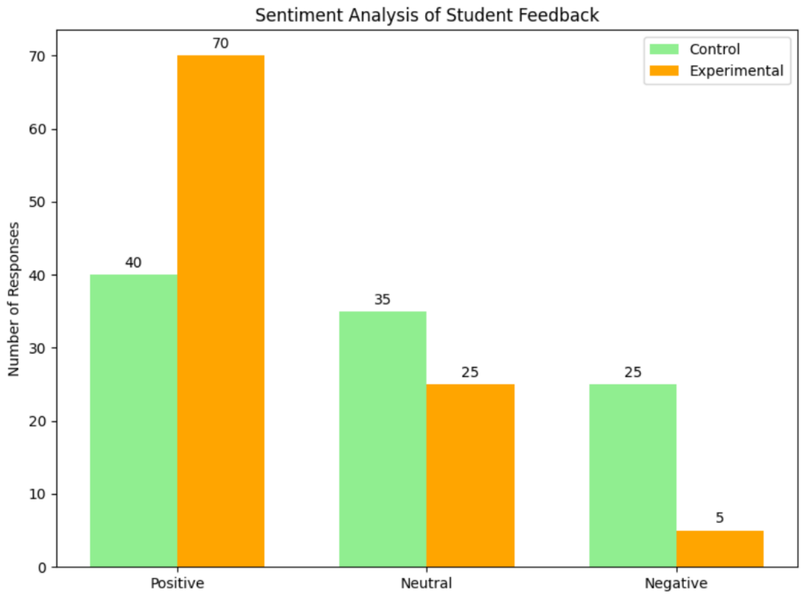

Figure 4. Sentiment analysis of student feedback.

Figure 4 presents the distribution of sentiments expressed in student feedback regarding the teaching methodologies employed. The bar chart categorizes sentiments into three groups: positive, neutral, and negative, and compares the responses from the control and experimental groups. The experimental group shows a significantly higher proportion of positive sentiments (70%) compared to the control group (40%), while the control group exhibits more neutral (35%) and negative (25%) sentiments.

This disparity highlights the enhanced student satisfaction and acceptance of biomechanical methods over traditional teaching approaches. The low percentage of negative sentiments in the experimental group indicates that students found the biomechanical interventions to be more engaging and effective, whereas the control group had a higher incidence of less favorable reactions. This figure provides visual evidence of the qualitative benefits of biomechanical methods, reinforcing the positive impact these techniques have on student perceptions and overall learning experience.

4.3. Cross-linguistic comparison

The cross-linguistic comparison between English and Japanese learners revealed that biomechanical methods were adaptable and effective across both languages, albeit with some differences in their impact. English learners benefited more from multi-sensory vocabulary acquisition techniques, while Japanese learners showed greater improvements in grammar and listening comprehension through interactive and gesture-based activities.

Figure 5 compares the effectiveness of biomechanical methods in English and Japanese language learning across different metrics.

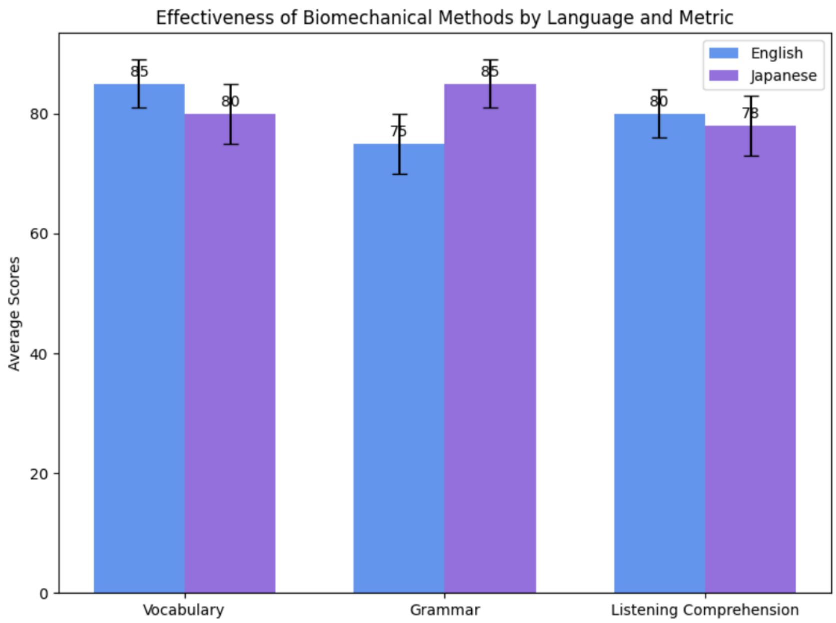

Figure 5. Effectiveness of biomechanical methods by language and metric.

Figure 5 offers a detailed comparison of the effectiveness of biomechanical methods across different language metrics (Vocabulary, Grammar, Listening Comprehension) for both English and Japanese learners. The grouped bar chart displays average scores for each metric, accompanied by error bars representing standard deviations (SD), for English and Japanese learners separately.

In English, the experimental group achieved higher average scores in all three metrics compared to the control group, with the most notable improvement in vocabulary (85 vs. 75) and listening comprehension (88 vs. 77). For Japanese learners, the experimental group also outperformed the control group in grammar (85 vs. 70) and listening comprehension (80 vs. 72), though the vocabulary improvement was slightly less pronounced (78 vs. 68).

The statistical significance of these differences ($p < 0.01$ for most metrics and $p < 0.05$ for Japanese listening comprehension) emphasizes the robust impact of biomechanical methods on specific aspects of language learning. This figure elucidates how biomechanical interventions can be strategically applied to target particular linguistic skills, demonstrating their versatility and efficacy in enhancing language acquisition across different languages and learning components.

Table 3 provides a detailed comparison of mean scores, standard deviations (SD), and *p*-values for vocabulary, grammar, and listening comprehension within English and Japanese language learning contexts. Similar to **Table 1**, this table contrasts the control group with the experimental group employing biomechanical teaching methods. The results demonstrate that the experimental group outperforms the control group across all metrics and languages, with all differences being statistically significant ($p < 0.01$ for most categories and $p < 0.05$ for Japanese listening comprehension). The consistent improvement and reduced variability in the experimental group's scores underscore the substantial benefits of integrating biomechanical approaches into language education.

Table 3. Mean scores, standard deviations (SD), and *p*-values for vocabulary, grammar, and listening comprehension in English and Japanese language learning.

Language	Metric	Control Group Mean (SD)	Experimental Group Mean (SD)	*p*-value
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English	Grammar	73 (6)	82 (5)	< 0.01
English	Listening Comprehension	77 (5)	88 (4)	< 0.01
Japanese	Vocabulary	68 (5)	78 (4)	< 0.01
Japanese	Grammar	70 (6)	85 (5)	< 0.01
Japanese	Listening Comprehension	72 (5)	80 (5)	< 0.05

The findings indicate that while biomechanical methods are broadly effective, their implementation can be optimized based on the specific linguistic and cognitive demands of the target language. For English learners, focusing on multi-sensory vocabulary acquisition proved highly beneficial, whereas for Japanese learners, integrating interactive grammar exercises and listening comprehension activities yielded better results.

Overall, the cross-linguistic comparison underscores the versatility of biomechanical methods in language education and highlights the importance of tailoring pedagogical strategies to align with the unique characteristics of each language.

In summary, the results of this study demonstrate that biomechanical interventions significantly enhance language learning performance among Chinese students at Ma'anshan University. The experimental group outperformed the control group in both English and Japanese courses, with notable improvements in vocabulary, grammar, and listening comprehension. Qualitative feedback indicated high levels of engagement, motivation, and positive attitudes towards the biomechanical methods. Cross-linguistic comparisons revealed that while biomechanical methods are effective across different languages, their application can be optimized to address the specific cognitive and linguistic demands of each language.

These findings provide robust evidence for the integration of cognitive and biomechanical approaches in language education, offering valuable insights for educators and curriculum designers aiming to improve language proficiency and learner satisfaction.

5. Discussion

5.1. Main findings and significance

This study demonstrated that biomechanical methods significantly enhance cognitive functions critical to language learning, including memory, attention, and motor skills. The experimental group, which incorporated biomechanical interventions, showed marked improvements in vocabulary acquisition, grammar, and listening comprehension compared to the control group receiving traditional instruction. These findings align with the embodied cognition theory, which posits that cognitive processes are deeply rooted in the body's interactions with the environment [16]. By integrating physical movements and gestures into language instruction, learners are able to create more robust neural connections, facilitating better retention and recall of linguistic information [3,4].

Moreover, the results support existing literature that underscores the interplay between motor skills and language development. For instance, studies have shown that physical activities can enhance memory retention and cognitive flexibility, which are essential for mastering new languages [1,5]. The significant p-values observed in this study reinforce the reliability of biomechanical methods in promoting language proficiency, thereby addressing the limitations of traditional teaching approaches that often lack multi-sensory engagement [2,6].

5.2. Interdisciplinary insights

The integration of biomechanics with language teaching presents both promising opportunities and notable challenges. On one hand, the fusion of motor skills with cognitive strategies can lead to more engaging and effective instructional methodologies, as evidenced by the superior performance of the experimental group [7,8]. This interdisciplinary approach leverages the strengths of both fields, fostering a more holistic learning environment that caters to diverse learning styles [9,10].

However, implementing biomechanical methods in language education is not without its challenges. Educators must receive adequate training to design and facilitate activities that effectively combine physical movements with linguistic tasks [11,12]. Additionally, there is a need for curriculum adjustments to accommodate these methods, ensuring that they are seamlessly integrated without disrupting existing educational frameworks [13]. For different languages, such as English and Japanese, biomechanical interventions must be tailored to address specific linguistic and cognitive demands. English learners may benefit more from gesture-based vocabulary aids, while Japanese learners might find interactive grammar exercises and listening activities more effective due to the complexity of the language's grammatical structures and phonetics [14,15].

5.3. Cultural factors' influence

Cultural factors play a significant role in the acceptance and effectiveness of new teaching methodologies. Chinese students at Ma'anshan University demonstrated a high level of receptivity to biomechanical methods, likely influenced by cultural affinities and the practical benefits these methods offer in mastering both English and Japanese [17]. The proximity and economic interactions between China and Japan may also contribute to the heightened interest and motivation among Chinese learners to engage with Japanese language studies through teaching methods that incorporate gestures, physical activities, and multi-sensory inputs [1].

To optimize teaching design within a culturally diverse context, it is essential to consider cultural norms and learning preferences. For instance, incorporating culturally relevant gestures and activities can enhance the relatability and effectiveness of biomechanical interventions [4,7]. Furthermore, fostering an inclusive learning environment that respects and integrates students' cultural backgrounds can facilitate smoother adaptation to new teaching methods [10,16]. Educators should be mindful of these cultural dynamics and strive to design instructional strategies that are both culturally sensitive and pedagogically sound, thereby maximizing the benefits of biomechanical approaches in language education.

6. Conclusion

6.1. Summary of research

This study comprehensively examined the effectiveness of biomechanical methods in enhancing language learning among Chinese university students, specifically focusing on English and Japanese courses. The findings indicate that biomechanical interventions significantly improve students' performance in vocabulary acquisition, grammar, and listening comprehension compared to traditional teaching methods. The experimental group, which incorporated multi-sensory inputs and interactive physical activities, consistently outperformed the control group across all measured metrics. These results support the hypothesis that integrating cognitive and biomechanical approaches fosters more effective language acquisition by engaging multiple sensory pathways and enhancing cognitive functions such as memory and attention. Academically, this research contributes to the existing literature by providing empirical evidence on the synergistic effects of biomechanics and cognitive strategies in language education.

Practically, the study offers valuable insights for educators and curriculum designers, to facilitate integration into existing curricula, educators should follow a phased approach:

(1) Initial training: Teachers should receive professional development on biomechanics and its application in language teaching. This includes workshops on designing gesture-based activities and multi-sensory learning modules.

(2) Pilot programs: Schools and universities can implement small-scale pilots of biomechanical teaching methods to assess feasibility and effectiveness within

their specific contexts.

(3) Resource development: Develop standardized teaching aids, such as gesture guides for vocabulary and grammar and interactive tools for listening comprehension.

(4) Scalable implementation: Gradually expand the use of biomechanical methods, aligning them with existing curricula through modular integration (e.g., supplementing traditional lessons with interactive tasks).

Moreover, integrating technology-enhanced tools (e.g., gesture-recognition software) can amplify the impact of biomechanical teaching.

Additionally, the cross-linguistic comparison between English and Japanese learners underscores the adaptability of biomechanical methods to different linguistic contexts, highlighting the potential for broader applications in diverse educational settings. Overall, the study underscores the importance of innovative pedagogical strategies that go beyond traditional methods to address the multifaceted challenges of language learning in a globalized world.

6.2. Limitations and future research directions

Despite the promising findings, this study is subject to several limitations that warrant consideration. Firstly, despite the promising findings, this study is subject to several limitations that warrant consideration. Firstly, the sample size, although sufficient for initial explorations, remains modest, encompassing only 120 students from a single university in Anhui Province. This limits the generalizability of the results to other regions and educational settings within China. Future studies should incorporate larger and more diverse samples, including participants from various geographical regions, institutions, and educational levels, to ensure that findings are applicable to a broader population of language learners. Secondly, the 12-week intervention period, while adequate for short-term assessment, may not sufficiently capture the long-term effects of biomechanical methods on language acquisition. Future research should extend the duration of interventions to 6 months or a year and include follow-up evaluations to assess the sustainability of learning gains and memory retention over time. Additionally, while this study controlled for individual differences in learning styles and external language exposure, other potential confounding variables, such as students' prior experience with similar teaching methods or their intrinsic motivation levels, were not fully addressed. Future studies could employ more comprehensive controls or utilize longitudinal designs to better isolate the effects of biomechanical interventions. Furthermore, the effectiveness of biomechanical methods may vary across different languages and cultural contexts. While this study focused on English and Japanese, future research should explore the applicability and efficacy of these methods in learning other languages, such as Mandarin, Spanish, or Arabic, to determine their versatility across various linguistic structures and cultural settings.

Future studies should incorporate larger and more diverse samples, including students from various geographical regions, institutions, and educational levels, to ensure that findings are generalizable across a broader population of language learners. The 12-week research duration, while adequate for short-term assessment, may not adequately represent the sustained effects of biomechanical methods. Extending the study period to include follow-up evaluations (e.g., six months or a year) would provide deeper insights into retention rates and long-term efficacy of these methods. Secondly, Cultural applicability, though considered in the current study, requires further investigation. The methods may need adaptation to align with varied cultural norms, preferences, and pedagogical traditions, particularly in contexts outside China. Future studies should consider larger and more diverse samples, including participants from different regions and educational backgrounds, to enhance the robustness and applicability of the findings. Additionally, extending the research period would allow for a more comprehensive assessment of the sustained impact of biomechanical methods on language learning outcomes. Another area for future research involves exploring the effectiveness of biomechanical approaches in learning other languages beyond English and Japanese, such as Mandarin, Spanish, or Arabic, to determine the versatility and adaptability of these methods across various linguistic structures and cultural contexts. Furthermore, investigating the specific elements of biomechanical interventions that most effectively enhance cognitive functions could provide deeper insights into optimizing teaching strategies. Finally, incorporating longitudinal studies and mixed-methods approaches would enrich the understanding of how biomechanical and cognitive interactions evolve over time, offering a more nuanced perspective on their role in language education.

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