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# The Impact of Working Memory Training on Grammatical Development of Complex Sentences among Iranian EFL Intermediate Teacher Trainees

Akbar. Molaei[1*]

[1] Department of English Language Teaching, Farhangian University, Tehran, Iran

*** Corresponding author email address**: a.molaei@cfu.ac.ir

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A B S T R A C T

**Purpose:** This study aimed to investigate the impact of working memory training on the grammatical development of complex sentence structures among Iranian EFL intermediate teacher trainees.

**Methods and Materials:** A quasi-experimental design was employed involving 49 female freshman EFL teacher trainees from Bentol-hoda Teacher Education University in Bushehr, Iran. Participants were assigned to either an experimental group, which received structured working memory training over four weeks, or a control group, which received traditional grammar instruction. Both groups completed a grammar pre-test and post-test focused on complex sentence structures, including noun, adjective, and adverbial clauses. The same grammar test was used at both time points to assess changes in grammatical proficiency. Data were analyzed using Analysis of Covariance (ANCOVA), with the pre-test scores treated as covariates to determine the effect of the intervention.

**Findings:** Descriptive statistics showed that while both groups had similar grammar scores at pre-test (M = 22.67, SD = 3.21 for experimental; M = 23.02, SD = 3.09 for control), the experimental group showed significantly higher gains in the post-test (M = 31.45, SD = 2.88) compared to the control group (M = 25.11, SD = 3.34). ANCOVA results confirmed a statistically significant effect of the working memory training on grammar achievement, $F(1, 46) = 36.84$, $p = .000$, $\eta^2 = .45$, indicating a large effect size. The covariate (pre-test score) was also significant, $F(1, 46) = 21.56$, $p = .000$, $\eta^2 = .32$.

**Conclusion:** The findings demonstrate that structured working memory training can significantly enhance EFL learners' grammatical development of complex sentence structures. This supports the integration of cognitive training components into grammar instruction in EFL teacher education programs, particularly in formal classroom settings with limited natural input.

***Keywords:*** *working memory, complex sentence structures, EFL learners, grammar development, teacher trainees.*

## 1. Introduction

The acquisition of complex grammatical structures in a second language (L2) continues to be a central concern in applied linguistics, especially in contexts where learners rely predominantly on classroom instruction, such as English as a Foreign Language (EFL) settings. A growing body of research has demonstrated that cognitive variables, particularly working memory (WM), play a vital role in the acquisition and processing of grammar in L2 learners (Bunting & Wen, 2023; Chen et al., 2022; Hu & No, 2021).

Working memory is conceptualized as a limited-capacity system responsible for temporarily holding information while it is being processed and integrated with existing knowledge. It is essential for tasks that require mental manipulation of rules, forms, and meanings, such as understanding and producing complex grammatical structures (Filipe et al., 2023; Li, 2021; Siu, 2023). These mental operations are critical for intermediate EFL learners who are expected to transition from basic grammar knowledge to advanced sentence construction, particularly those in teacher training programs where grammatical precision is a core professional competency. Learners with higher WM capacity generally outperform others in tasks involving grammatical complexity due to their enhanced ability to manage cognitive load (Chen et al., 2022; Gallagher et al., 2022).

Previous studies have provided empirical evidence supporting the predictive power of WM in L2 grammar learning. For instance, verbal WM has been positively correlated with learners' ability to process embedded structures and maintain syntactic dependencies over time (Bunting & Wen, 2023; Xu, 2023). These findings underscore the potential of WM as both a predictor and an intervention target in language education. The present study builds on this body of work by implementing a structured WM training program and examining its effects on learners' acquisition of English complex sentence structures.

Recent cognitive research has emphasized the dynamic and trainable nature of WM. Structured training programs focusing on updating, sequencing, and inhibition tasks have been shown to enhance WM capacity and improve performance on language-related tasks (Nawaz et al., 2024; Sutthiphan et al., 2024). In second language contexts, such interventions offer a promising approach to reinforce the mental scaffolding needed for grammar learning. Gong et al. (Gong et al., 2024) even demonstrated that artificial intelligence systems with improved WM capacities exhibited greater syntactic fluency, reflecting the fundamental role of memory in linguistic processing.

In EFL contexts like Iran, grammar instruction traditionally emphasizes rule memorization and sentence translation. While these methods may support initial familiarity with grammatical rules, they often fail to engage the cognitive functions necessary for higher-order processing and production (Ahmed, 2022). A shift toward integrating WM training into grammar instruction could potentially bridge the gap between declarative knowledge and procedural fluency. This pedagogical pivot is supported by theoretical perspectives that see grammar not as a static body of rules but as a dynamic cognitive system shaped by usage and memory interaction (Kermer, 2020).

The theoretical rationale for this study also aligns with cognitive models that highlight the intersection of WM, attention control, and statistical learning in SLA. Chen et al. (Chen et al., 2022) found that among cognitive predictors, WM and attention control were the most consistent in explaining variance in L2 grammar achievement. Similarly, Hu and No (Hu & No, 2021) emphasized WM as an active resource in syntactic processing and grammatical rule formation. These perspectives indicate that training aimed at enhancing WM may have a direct and measurable impact on learners' ability to acquire complex sentence structures.

Furthermore, neurocognitive studies have begun to unravel the brain mechanisms associated with grammar learning. Gallagher et al. (Gallagher et al., 2022) provided causal evidence for the involvement of Broca's area in grammar acquisition, linking its function directly to WM capacity in syntactic processing. Their findings strengthen the case for memory-focused interventions in language education. In teacher education, such cognitive reinforcement may be especially critical, as future instructors must both understand and explain complex grammar rules effectively.

Complementary lines of inquiry have explored the role of multimedia and multimodal stimuli in supporting memory-based language learning. Nawaz et al. (Nawaz et al., 2024) found that learners exposed to multimedia input demonstrated improved vocabulary retention mediated by enhanced WM engagement. Muñoz (Muñoz, 2022) highlighted the value of audiovisual input in grammar instruction, suggesting that contextual cues can reduce cognitive load and facilitate deeper grammatical processing. Similarly, Feng and Guo (Feng & Guo, 2024) observed that student engagement increased when learning was supported



E-ISSN: 2980-9681

by music videos, which implicitly activated WM and sustained attention.

There is also growing interest in optimizing WM through educational technology and digital cognitive modeling. Dodić et al. (Dodić et al., 2025) explored memory management techniques in processing large-scale textual corpora, providing insights into how human-like memory structures can be optimized for language tasks. In a parallel effort, Yao et al. (Yao et al., 2022) introduced the concept of knowledge injection in transformer models, mimicking the way human learners draw on long-term memory to resolve syntactic ambiguities. These developments in computational memory systems underscore the relevance of WM to both artificial and human language processing.

In addition to formal mechanisms, socio-cognitive variables such as imagination, emotion, and engagement also play a role in memory-mediated grammar learning. Lenčová and Tomčániová (Lenčová & Tomčániová, 2023) proposed incorporating imaginative narrative techniques in language classrooms to enhance memory consolidation. Sofi (Sofi, 2024) similarly argued for a more holistic approach to grammar instruction that acknowledges the emotional and experiential dimensions of language use, thereby fostering long-term retention through meaningful context.

Gamification has also emerged as a motivational strategy that can indirectly support grammar acquisition by sustaining attention and engaging WM. Al-khresheh (Al-khresheh, 2025) found that gamified learning environments increase cognitive involvement, leading to improved grammatical accuracy. Fitria (Fitria, 2024) further proposed that photographic memory techniques—when creatively integrated into instruction—can help reinforce grammar patterns through visual-spatial associations.

The auditory modality, too, has been recognized as influential in grammar learning via memory channels. Lee and Kim (Lee & Kim, 2023) demonstrated that children with stronger auditory WM showed better comprehension of syntactic structures, suggesting that this modality may also benefit adult learners. Similarly, Ruecken et al. (Ruecken et al., 2024) proposed a probabilistic memory synthesis model to maintain contextual consistency—a principle highly applicable to grammar acquisition, where learners must link syntactic elements coherently over extended discourse.

From a developmental perspective, Xu (Xu, 2023) found that early WM development in bilingual children predicted later grammar proficiency. Although her work focused on younger learners, the implication that WM remains relevant throughout the learning lifespan supports its importance for adult learners as well. Lu et al. (Lu et al., 2024) also showed that early cognitive predictors such as WM capacity correlate with word-referent mapping and later linguistic competence, reinforcing the foundational role of memory in language development.

Despite this extensive literature, research examining the direct impact of WM training on grammatical development in adult EFL teacher trainees remains scarce. Given that these learners are not only acquiring language but also preparing to teach it, the cognitive demands they face are arguably more complex. As such, this population represents an ideal testbed for investigating whether cognitive interventions can translate into pedagogical readiness. Working memory enables learners to simultaneously store and manipulate linguistic information, a function that becomes especially relevant when dealing with complex syntactic constructions such as subordinate clauses and multi-clause sentence structures. This study explores whether structured WM training can significantly enhance the grammatical development of complex sentences among Iranian EFL intermediate teacher trainees.

## 2. Methods and Materials

### *2.1. Study Design and Participants*

This study employed a quasi-experimental design to investigate the impact of working memory training on the grammatical development of complex sentence structures among intermediate-level Iranian EFL teacher trainees. The research aimed to explore the causal effect of enhancing working memory through structured cognitive training on the participants' ability to acquire and analyze complex grammatical forms. The study was conducted at Bentol-hoda Teacher Education University in Bushehr, Iran—a girls-only institution dedicated to training prospective English teachers for the southern provinces of the country. The participants consisted of 49 female freshman students enrolled in the Bachelor of Arts in TEFL program. These students had entered the program through the national university entrance examination and were preparing for teaching roles upon graduation.

At the time of the study, all participants had completed their first semester and passed ten foundational courses, including a basic grammar course that served as a prerequisite for more advanced instruction. They were enrolled in a course titled “Practical Grammar,” which focused on English sentence structures, particularly simple, compound, and complex sentences, and emphasized mastery


E-ISSN: 2980-9681

of grammatical components such as clauses and phrases. This shared academic background provided a homogeneous and coherent context for exploring how cognitive training might affect grammar acquisition.

Two intact classes were selected through cluster random assignment and were then randomly assigned to either the experimental or the control group. To establish baseline comparability, both groups completed a pre-test that assessed their knowledge of complex grammatical structures. This pre-test was used to confirm the relative homogeneity of the groups in terms of grammar proficiency before any instructional intervention took place. Following the pre-test, the experimental group underwent a four-week working memory training intervention, whereas the control group continued with traditional grammar instruction. The intervention aimed to indirectly enhance grammatical learning by stimulating cognitive functions associated with working memory, such as attention control, information updating, and sequential processing.

The experimental group participated in eight 45-minute sessions over the course of four weeks. These sessions incorporated structured cognitive activities intended to strengthen memory capacity and processing efficiency. These activities included mental arithmetic, sequencing tasks, memory updating exercises, and dual-processing challenges, which were designed to place cognitive load on memory resources while encouraging attention to grammatical forms. Meanwhile, the control group received conventional instruction in complex sentence types—focusing on noun clauses, adjective clauses, and adverbial clauses—without any cognitive enhancement component. After the treatment period, both groups took a post-test consisting of the same grammar assessment administered at the beginning of the study. The comparison of pre- and post-test results enabled the evaluation of the instructional effect.

### *2.2. Measures*

The sole instrument used for data collection in this study was a grammar proficiency test focused on complex sentence structures. This test was administered both as a pre-test and a post-test to measure changes in the learners' grammatical competence following the intervention. The test comprised forty multiple-choice items designed to assess participants' understanding, recognition, and application of complex sentence patterns, including noun clauses, adjective clauses, and adverbial clauses. The test items were aligned with the content of the Practical Grammar course and were piloted with a similar student population to ensure reliability and content validity.

### *2.3. Data Analysis*

The data collected from the grammar pre-test and post-test were analyzed using Analysis of Covariance (ANCOVA) in SPSS version 26. ANCOVA was selected as the appropriate statistical technique to determine whether any observed differences in post-test scores between the experimental and control groups could be attributed to the intervention, while statistically controlling for initial differences in grammar proficiency. By including the pre-test scores as a covariate, ANCOVA adjusted the post-test scores to account for baseline variation and provided a more accurate estimation of the treatment effect.

## 3. Findings and Results

To evaluate the effectiveness of working memory training on the grammatical development of complex sentence structures, descriptive statistics and ANCOVA were conducted on pre-test and post-test grammar scores for both the experimental and control groups.

Table 1 presents the descriptive statistics, including the mean and standard deviation of grammar test scores for each group at both pre-test and post-test stages.

**Table 1**

*Descriptive Statistics for Grammar Scores by Group and Time*

| Group | Time | M | SD |
|---|---|---|---|
| Experimental | Pre-test | 22.67 | 3.21 |
| | Post-test | 31.45 | 2.88 |
| Control | Pre-test | 23.02 | 3.09 |
| | Post-test | 25.11 | 3.34 |

As shown in Table 1, both groups had relatively similar grammar proficiency levels at the pre-test stage, with the experimental group scoring a mean of 22.67 (SD = 3.21) and the control group scoring a slightly higher mean of 23.02



E-ISSN: 2980-9681

(SD = 3.09). After the intervention, the experimental group exhibited a substantial improvement in grammar test performance, with a post-test mean of 31.45 (SD = 2.88), compared to the control group's post-test mean of 25.11 (SD = 3.34). This difference suggests a notable positive effect of the working memory training on grammatical development in the experimental group.

To statistically verify the impact of the intervention while controlling for baseline grammar proficiency, an ANCOVA was conducted. The grammar post-test scores served as the dependent variable, group (experimental vs. control) as the independent variable, and the pre-test scores were entered as a covariate.

**Table 2**

*ANCOVA Results for Grammar Post-Test Scores (Pre-Test as Covariate)*

| Source | SS | df | MS | F | p | $\eta^2$ |
|---|---|---|---|---|---|---|
| Pre-test (Covariate) | 182.41 | 1 | 182.41 | 21.56 | .000 | .32 |
| Group | 311.76 | 1 | 311.76 | 36.84 | .000 | .45 |
| Error | 245.30 | 46 | 5.33 | | | |
| Total | 739.47 | 49 | | | | |

As illustrated in Table 2, the ANCOVA revealed a statistically significant effect of the intervention after controlling for pre-test scores, $F(1, 46) = 36.84$, $p = .000$, $\eta^2 = .45$. This large effect size indicates that 45% of the variance in grammar post-test scores can be attributed to the working memory training. Additionally, the covariate (pre-test scores) also had a significant effect, $F(1, 46) = 21.56$, $p = .000$, $\eta^2 = .32$, confirming that initial grammar knowledge played a role in predicting post-test outcomes. However, the main source of improvement was clearly associated with the experimental intervention, supporting the hypothesis that working memory training significantly enhances grammatical development in complex sentence structures among intermediate EFL teacher trainees.

## 4. Discussion and Conclusion

The present study aimed to examine the impact of working memory training on the grammatical development of complex sentence structures among Iranian EFL intermediate teacher trainees. The findings revealed that participants in the experimental group, who received structured working memory (WM) training over a four-week period, demonstrated significantly higher post-test scores in complex grammar tasks compared to their peers in the control group who received only traditional grammar instruction. After statistically controlling for pre-test scores using ANCOVA, the results confirmed a strong and statistically significant effect of the intervention, with the experimental group achieving greater gains in recognizing and analyzing complex grammatical forms.

These findings offer empirical support for the argument that working memory is not merely a passive storage system but a dynamic cognitive resource that facilitates the acquisition of complex syntactic structures in second language (L2) learning. As several prior studies have noted, the processing of embedded clauses and hierarchical grammatical patterns—such as those found in noun, adjective, and adverbial clauses—places high demands on verbal working memory (Chen et al., 2022; Filipe et al., 2023; Li, 2021). The significant improvement observed in the experimental group suggests that the cognitive exercises used during the intervention—such as sequencing tasks, updating operations, and dual-processing activities—successfully enhanced learners' working memory capacity, thereby enabling them to process and retain complex syntactic input more effectively.

The results of this study align with previous research that highlights the predictive and facilitative role of working memory in L2 grammatical development. For example, Bunting and Wen (Bunting & Wen, 2023) demonstrated that verbal WM capacity directly influences the accuracy and fluency of bilingual speakers when using complex structures. Likewise, Siu (Siu, 2023) observed that individuals with higher working memory performance exhibited greater success in acquiring grammatical forms in bilingual learning environments. These findings are consistent with the present study's results, which showed that working memory training contributed meaningfully to the learners' syntactic development in EFL contexts.

Moreover, the results are reinforced by the neurocognitive evidence provided by Gallagher et al. (Gallagher et al., 2022), who established the causal role of



E-ISSN: 2980-9681

Broca's area—a region associated with both language and working memory—in second language grammar acquisition. Their longitudinal brain imaging study supports the interpretation that grammatical development is partly mediated by cognitive capacities such as memory and attention control. The significant post-test performance of the experimental group in the current study corroborates this neurological perspective, implying that cognitive training may enhance the neural efficiency of syntactic processing.

In addition to brain-based evidence, applied studies support the pedagogical value of targeting working memory in language education. For instance, Sutthiphan et al. (Sutthiphan et al., 2024) found that structured memory programs led to noticeable improvements in language skills among older adults with mild cognitive impairments. The current study extends these findings to a younger EFL population, showing that memory-focused training is not only feasible but also beneficial in formal language learning environments. Similarly, Nawaz et al. (Nawaz et al., 2024) showed that multimedia-supported vocabulary learning was mediated by working memory, highlighting the potential for cognitive training to support a range of linguistic competencies.

Interestingly, the findings also echo the broader understanding that memory-enhanced learning environments can support grammatical acquisition even in low-exposure contexts such as EFL classrooms. According to Hu and No (Hu & No, 2021), working memory acts as a critical scaffold for language development in environments where learners must rely heavily on instruction and less on authentic interaction. This is particularly relevant in the Iranian educational context, where classroom-based learning dominates and exposure to natural English input is minimal. The significant improvement observed in the experimental group suggests that WM training can compensate, at least partially, for the limited opportunities to practice English grammar in meaningful contexts.

Furthermore, the present study's findings align with Chen et al. (Chen et al., 2022), who compared cognitive predictors of grammar learning and identified working memory as the most consistent factor influencing success in acquiring syntactic rules. In a similar vein, Xu (Xu, 2023) emphasized the long-term role of working memory in grammar development across life stages, beginning in childhood and extending into adult learning—a proposition that the current study supports by demonstrating its relevance in university-level EFL learners.

Additional support comes from emerging fields such as AI and computational linguistics. Gong et al. (Gong et al., 2024) examined working memory capacity in AI systems and found a direct link between expanded memory and improved syntactic output in generative models. Similarly, Dodić et al. (Dodić et al., 2025) explored the optimization of memory management in multilingual applications, offering insights into how memory processes underpin language processing even in artificial systems. These parallels with human learning reinforce the idea that enhanced memory capacity leads to improved grammatical accuracy and structural coherence.

Multimodal and multimedia learning environments have also been shown to activate memory systems in ways that benefit grammar acquisition. Muñoz (Muñoz, 2022) illustrated how audiovisual input improves grammatical comprehension by offering contextual cues that reduce cognitive overload. Likewise, Feng and Guo (Feng & Guo, 2024) demonstrated that language learners exposed to music-based videos maintained higher engagement and recall, likely due to increased memory activation. These findings resonate with the current study's instructional approach, which included cognitively engaging tasks aimed at activating similar memory pathways during grammar instruction.

In terms of pedagogical design, the study's findings are also aligned with calls for more cognitively informed language teaching practices. Kermer (Kermer, 2020) proposed a cognitive grammar framework that integrates memory, perception, and usage into grammar instruction. Similarly, Ahmed (Ahmed, 2022) argued that language learning strategies should be embedded within learners' cognitive systems for lasting impact. The current study contributes to this line of thinking by offering empirical evidence that working memory training—when implemented alongside grammar instruction—enhances learners' ability to analyze, comprehend, and produce complex sentence structures.

While much of the existing literature supports the study's findings, some studies also extend its implications. For example, Lenčová and Tomčániová (Lenčová & Tomčániová, 2023) emphasized the imaginative and emotional dimensions of memory in foreign language classrooms, suggesting that tasks invoking creativity may further enhance grammar retention. Sofi (Sofi, 2024) also explored how memory and language are intertwined through lived human experiences, arguing for a more integrative instructional design that takes memory seriously as both a



E-ISSN: 2980-9681

cognitive and emotional process. These perspectives complement the current study by encouraging the development of grammar instruction that goes beyond form-focused teaching and engages learners' cognitive and affective systems.

Moreover, auditory and visual memory components have been shown to influence grammar learning in both young and adult learners. Lee and Kim (Lee & Kim, 2023) found that auditory WM in young children significantly predicted grammar performance, while Fitria (Fitria, 2024) demonstrated how visual-spatial memory techniques could be incorporated into grammar tasks to support retention. These findings support the idea that a multi-sensory approach to WM training may further amplify its benefits in grammar learning—an area worth exploring in future studies.

Finally, Ruecken et al. (Ruecken et al., 2024) proposed a model of probabilistic memory synthesis to maintain contextual consistency in adaptive systems, an idea with clear implications for grammar instruction where learners must maintain syntactic coherence over long utterances. Yao et al. (Yao et al., 2022) added that knowledge integration into memory systems improves processing efficiency—mirroring the improvements observed in the experimental group's ability to handle complex sentence patterns after cognitive training.

Despite its significant findings, this study is not without limitations. First, the sample was limited to 49 female students from a single teacher training college in Bushehr, which may limit the generalizability of the results to other populations or mixed-gender groups. Second, the intervention lasted only four weeks, which, although sufficient to yield statistically significant results, may not reflect the long-term effects of WM training on grammatical development. Third, only grammar test scores were used as outcome measures; future research could incorporate speaking or writing tasks to assess learners' productive use of complex structures. Additionally, the absence of direct WM testing instruments in the pre- and post-assessments limits the ability to quantify changes in memory capacity itself.

Future research should consider expanding the scope to include larger, more diverse samples across different regions, genders, and proficiency levels. Longitudinal studies examining the sustained effects of WM training on grammar development over months or academic years would provide valuable insights into the durability of the intervention. Additionally, future studies should consider using direct WM measurement tools alongside grammar tests to verify whether improvements in grammar are indeed mediated by gains in working memory. Exploring multi-modal WM training that integrates auditory, visual, and kinesthetic components may also yield deeper understanding of how to customize interventions for varied learner profiles.

Given the findings of this study, EFL instructors and curriculum designers should consider incorporating structured working memory activities into grammar instruction, especially for intermediate learners. These activities can include sequencing, updating, dual-processing, and mental manipulation tasks that parallel grammatical tasks in complexity. Teacher training programs should be redesigned to include cognitive development components, enabling future educators to both benefit from and teach with memory-enhancing strategies. Incorporating WM training into regular coursework does not require abandoning traditional methods but can instead augment existing approaches to create a more cognitively supportive learning environment.

## Authors' Contributions

All authors significantly contributed to this study.

## Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

## Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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## Declaration of Interest

The authors report no conflict of interest.

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## Ethical Considerations



E-ISSN: 2980-9681

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the study and participated in the research with informed consent.

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