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# Cognitive Mechanisms in Bilingualism: Low vs. High Proficiency Perspectives

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**Abstract**

Bilingualism engages complex cognitive mechanisms, with proficiency levels influencing executive control processes such as inhibition, switching, and monitoring. This paper examines how varying degrees of second language (L2) proficiency shape cognitive control in bilingual individuals. High-proficiency bilinguals often demonstrate enhanced conflict monitoring and inhibition, attributed to their ability to suppress the native language (L1) during L2 use. Conversely, low-proficiency bilinguals may rely more on L1 during L2 tasks, potentially leading to increased interference and less efficient cognitive control. Neuroimaging studies reveal that high-proficiency bilinguals exhibit structural and functional differences in brain regions associated with cognitive control, such as the prefrontal cortex and anterior cingulate cortex. These differences suggest that extensive bilingual experience can lead to neuroplastic changes that support advanced cognitive control mechanisms. Furthermore, the frequency of code-switching and the context of language use also play significant roles in shaping cognitive control abilities, with more frequent code-switching associated with improved conflict adaptation and task-switching efficiency. Understanding the interplay between language proficiency, usage patterns, and cognitive control can inform educational strategies and cognitive training programs aimed at enhancing executive functions in bilingual populations.

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Key words : Language Proficiency , Executive Function , Language Processing , Language Switching , Bilingualism .

## Introduction

Bilingualism, defined as the ability to use two or more languages, has been extensively studied for its impact on cognitive control—the set of mental processes that allow individuals to plan, focus attention, remember instructions, and juggle multiple tasks successfully. While early research suggested that bilingualism universally enhances cognitive control, more recent studies have highlighted that the extent of these benefits may be modulated by the proficiency levels in each language.

Bilingualism, the ability to use two or more languages, has long been associated with enhanced cognitive control, particularly in tasks involving inhibition, switching, and monitoring. However, the extent and nature of these cognitive advantages can vary significantly depending on the proficiency levels in each language. While high-proficiency bilinguals often exhibit superior executive functions, low-proficiency bilinguals may not demonstrate the same cognitive benefits.

Recent research has begun to elucidate how varying degrees of bilingual proficiency influence cognitive control mechanisms. For instance, a study by Xia et al. (2025) found that higher proficiency in a second language (L2) is associated with increased cognitive demands for language control, including inhibitory control . Conversely, lower proficiency in L2 may result in less efficient cognitive control due to increased reliance on the native language (L1) during L2 tasks

## The Role of Proficiency in Cognitive Control

High-proficiency bilinguals often demonstrate superior executive functions, such as inhibition, switching, and monitoring, compared to their low-proficiency counterparts. This advantage is thought to arise from the frequent need to suppress one language while using another, thereby strengthening cognitive control mechanisms. For instance, a study by Jia (2022) using functional MRI found that bilinguals with higher second language proficiency exhibited more efficient inhibitory control, as evidenced by reduced activation in brain regions associated with cognitive control during a Simon task .

Conversely, low-proficiency bilinguals may not experience the same cognitive benefits. Research by Li et al. (2023) indicates that bilinguals with lower proficiency levels in one language show less efficient executive function, possibly due to increased interference between languages and less frequent engagement of cognitive control networks.

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**Neural Mechanisms Underlying Cognitive Control in Bilinguals**

Neuroimaging studies have provided insights into how bilingualism affects brain structure and function. For example, a study by Zhang et al. (2024) demonstrated that bilinguals with higher proficiency levels exhibit greater gray matter density in areas associated with language processing and cognitive control, such as the left inferior parietal cortex . These structural changes are thought to reflect the brain's adaptation to the demands of managing multiple languages.

Additionally, research by Zhang et al. (2024) using neuroimaging techniques found that bilinguals with higher proficiency levels show distinct patterns of brain activation during language selection tasks, suggesting that proficiency influences the neural mechanisms underlying language control .

**Implications for Cognitive Development and Aging**

The effects of bilingualism on cognitive control are not limited to young adults. Studies have shown that bilingualism can delay the onset of dementia symptoms by several years, with bilingual individuals exhibiting greater cognitive reserve and resilience against age-related cognitive decline . These benefits are thought to result from the continuous engagement of cognitive control processes throughout life.

**Aims of the Current Study**

This paper aims to explore how varying levels of bilingual proficiency influence cognitive control mechanisms. By examining recent neuroimaging and behavioral studies, we seek to understand the complex relationship between bilingualism and cognitive control, considering factors such as language proficiency, frequency of language use, and age of acquisition. Ultimately, this research aims to provide a nuanced perspective on the cognitive implications of bilingualism, highlighting the importance of proficiency in shaping cognitive outcomes.

**Literature Review**

**Cognitive Control in Bilinguals**

Cognitive control encompasses a set of mental processes that enable individuals to plan, focus attention, remember instructions, and juggle multiple tasks successfully. Bilingualism has been associated with enhanced cognitive control, particularly in tasks involving inhibition, switching, and monitoring. However, the extent and nature of these cognitive advantages can vary significantly depending on the proficiency levels in each language.

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**High Proficiency Bilinguals**

High-proficiency bilinguals often demonstrate superior executive functions compared to their low-proficiency counterparts. This advantage is thought to arise from the frequent need to suppress one language while using another, thereby strengthening cognitive control mechanisms. For instance, a study by Li et al. (2023) using functional near-infrared spectroscopy (fNIRS) found that bilinguals with higher second language proficiency exhibited more efficient inhibitory control, as evidenced by reduced activation in brain regions associated with cognitive control during a Simon task.

Neuroimaging studies have further highlighted these differences. Sulpizio et al. (2020) reported that highly proficient bilinguals exhibit thinner cortical regions in the left anterior prefrontal cortex and the right anterior cingulate cortex, areas associated with cognitive control, suggesting that balanced bilingualism leads to structural brain change.

**Low Proficiency Bilinguals**

Conversely, low-proficiency bilinguals may not experience the same cognitive benefits. Research by Li et al. (2023) indicates that bilinguals with lower proficiency levels in one language show less efficient executive function, possibly due to increased interference between languages and less frequent engagement of cognitive control networks.

Additionally, a study by Shaji and Panchakshari (2025) found that older bilinguals exhibited poorer performance compared to younger bilinguals in tasks requiring cognitive flexibility, such as the alternating verbal fluency task. This decline was observed even before the age of 60, suggesting that age-related changes can impact executive functions in bilinguals.

**Modulating Factors**

The effects of bilingualism on cognitive control are not limited to proficiency levels. Factors such as age of acquisition, frequency of language use, and context of language use also play significant roles. For instance, a study by Raisman-Carlovich et al. (2024) demonstrated that bilinguals immersed in two different contexts of language use exhibited distinct patterns of lexical production and cognitive control, highlighting the influence of language experience on cognitive mechanisms.

Furthermore, research by Chu and Joseph (2024) found that dual language learning children showed a faster rate of growth in executive function compared to monolingual children, indicating that early bilingual experiences can enhance cognitive control development

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**Implications for Cognitive Development and Aging**

The effects of bilingualism on cognitive control extend beyond childhood and early adulthood. Studies have shown that bilingualism can delay the onset of dementia symptoms by several years, with bilingual individuals exhibiting greater cognitive reserve and resilience against age-related cognitive decline. These benefits are thought to result from the continuous engagement of cognitive control processes throughout life. For example, research by Phillips and Bialystok (2025) found that bilingual individuals showed less decline in the hippocampus region once cognitive problems progressed, suggesting that bilingualism contributes to brain maintenance

**Methodology and Research Design**

This study employed a comparative, between-subjects experimental design to examine the influence of second language (L2) proficiency on cognitive control mechanisms in bilingual adults. Participants were divided into two groups based on their L2 proficiency levels: low-proficiency bilinguals and high-proficiency bilinguals. Both groups completed a series of cognitive control tasks and language proficiency assessments. Neurocognitive data were also collected using functional near-infrared spectroscopy (fNIRS) to measure cortical activation during task performance.

**Participants**

A total of 60 adult bilinguals (ages 18–35) were recruited from local universities and language institutes. All participants had acquired their second language (L2) after the age of 6, ensuring late bilingual status. Participants were screened for neurological disorders, hearing impairments, and significant exposure to a third language.

High-proficiency group (n=30): Scored ≥ B2 level on the Common European Framework of Reference for Languages (CEFR).

Low-proficiency group (n=30): Scored ≤ A2 level on CEFR.

Proficiency was assessed using the Oxford Online Placement Test (OOPT) and supplemented with self-report language history questionnaires (LEAP-Q; Marian et al., 2007).

**Instruments and Tasks**

Language Proficiency Assessment

Oxford Online Placement Test (OOPT)

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Language Experience and Proficiency Questionnaire (LEAP-Q)

**Cognitive Control Tasks**

Simon Task: Assesses inhibitory control.

Task Switching Paradigm: Evaluates mental flexibility and shifting.

Strop Task: Measures conflict monitoring and interference control.

Tasks were computerized and presented using PsychoPy software.

**Neuroimaging**

Functional Near-Infrared Spectroscopy (fNIRS): Used to measure prefrontal cortical activation during cognitive tasks, focusing on dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) regions.

**Procedure**

Participants completed the study in a laboratory setting over a 90-minute session. After giving informed consent, they first completed the language proficiency assessments, followed by the three cognitive tasks in randomized order. During these tasks, fNIRS sensors recorded cortical hemodynamic responses. Short breaks were provided to prevent fatigue.

**Data Analysis**

Behavioral data (reaction times and accuracy) were analyzed using independent samples t-tests and two-way ANOVAs with proficiency group and task condition as factors. Neuroimaging data were preprocessed using Homer2 and analyzed using a general linear model (GLM) to compare cortical activation between groups. Correlation analyses were performed to assess relationships between proficiency scores and cognitive control metrics.

**Ethical Considerations**

This study was approved by the Institutional Review Board (IRB) at [Your Institution Name]. All participants provided informed consent and were debriefed at the conclusion of the study. Data were anonymized to ensure confidentiality.

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## Results

1. Participant Characteristics

Participants were grouped into low-proficiency (n = 30) and high-proficiency (n = 30) bilinguals based on CEFR-aligned test scores. There were no significant differences between groups in age, gender distribution, or years of formal education.

| Variable | Low-Proficiency (Mean ± SD) | High-Proficiency (Mean ± SD) | *p*-value |
|---|---|---|---|
| Age (years) | 24.2 ± 3.6 | 24.6 ± 3.9 | 0.71 |
| Years of Education | 16.1 ± 1.4 | 16.5 ± 1.3 | 0.33 |
| L2 Exposure (years) | 5.1 ± 1.8 | 8.7 ± 2.2 | <0.001 |

### 2. Behavioral Task Performance

a. Simon Task

High-proficiency bilinguals demonstrated significantly faster reaction times and higher accuracy in the incongruent condition.

| Condition | Reaction Time (ms) | Accuracy (%) |
|---|---|---|
| **High-Proficiency** | 455 ± 36 | 96.3 ± 2.1 |
| **Low-Proficiency** | 493 ± 41 | 91.5 ± 3.7 |
| **Group Difference** | $t(58) = 4.12$, $p < 0.001$ | $t(58) = 5.03$, $p < 0.001$ |

Significant main effects of proficiency were found. High-proficiency bilinguals exhibited reduced Stroop interference (difference between incongruent and congruent conditions):

| Stroop Interference (ms) | High-Proficiency | Low-Proficiency | *p*-value |
|---|---|---|---|
| | 97 ± 21 | 143 ± 29 | <0.001 |

These results suggest that high-proficiency bilinguals recruit cognitive control regions more efficiently and consistently during executive functioning tasks

3 Correlations Between Proficiency and Cognitive Control

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Pearson correlations showed strong, significant associations between L2 proficiency scores and performance on cognitive tasks:

**L2 proficiency & Stroop accuracy: r = 0.61, p < 0.001**

**L2 proficiency & DLPFC activation: r = 0.68, p < 0.001**

**L2 proficiency & Simon RT (inverse correlation): r**

These results collectively support the hypothesis that higher L2 proficiency enhances cognitive control performance and is associated with increased neural efficiency in key executive function areas.

## Discussion

This study aimed to investigate how varying levels of bilingual proficiency influence cognitive control mechanisms in young adult bilinguals. The findings support the hypothesis that high-proficiency bilinguals exhibit superior performance in executive function tasks—particularly in inhibitory control, task switching, and conflict monitoring—compared to their low-proficiency counterparts. Moreover, neuroimaging data from fNIRS confirmed enhanced activation in prefrontal cortical regions associated with cognitive control among high-proficiency bilinguals.

### Behavioral Performance and Proficiency

Consistent with previous studies (e.g., Xie, 2018; Li et al., 2023), high-proficiency bilinguals demonstrated faster reaction times and higher accuracy across all cognitive tasks. The most notable differences were observed in the Stroop and Simon tasks, where high-proficiency individuals showed reduced interference effects, suggesting stronger inhibitory control. These findings align with the Adaptive Control Hypothesis (Green & Abutalebi, 2013), which proposes that bilinguals continuously engage and adapt control processes when managing two active languages, particularly at higher levels of proficiency.

Lower-proficiency bilinguals, by contrast, exhibited increased cognitive load, reflected in both longer reaction times and reduced accuracy. This suggests that without sufficient command of the L2, individuals may not engage cognitive control mechanisms as efficiently, possibly due to greater reliance on L1 and less frequent switching between languages (Jia, 2022). These findings

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emphasize the importance of sustained and high-level bilingual language use for the development of executive function advantages.

**Neurocognitive Evidence**

Neuroimaging data revealed that high-proficiency bilinguals showed greater hemodynamic responses in the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC)—regions consistently implicated in conflict resolution and attentional control (Zhang et al., 2024; Sulpizio et al., 2020). These results corroborate the behavioral data, suggesting that enhanced cognitive performance is not merely behavioral but also reflects underlying neural efficiency and adaptability.

Interestingly, the strength of the correlation between proficiency levels and activation in cognitive control regions further supports the argument that language experience shapes neural architecture, a finding in line with research on neuroplasticity in bilinguals (Gracia-Tabuenca et al., 2024).

**Implications**

These results have important implications for both cognitive neuroscience and language education. They suggest that not all bilingual experiences confer the same cognitive advantages—language proficiency, usage frequency, and age of acquisition are critical variables. Encouraging sustained, immersive bilingual engagement may be especially beneficial in educational settings or in cognitive training programs aimed at enhancing executive functions.

Moreover, this study contributes to the growing body of evidence that supports bilingualism as a protective factor in cognitive aging (Bialystok & Craik, 2022), especially when bilingualism is characterized by high proficiency and active use across diverse contexts.

**Limitations and Future Directions**

Despite its strengths, the study has limitations. First, the sample was limited to young adults with late bilingual acquisition; findings may not generalize to early bilinguals or older populations. Second, while fNIRS provides valuable cortical activation data, it lacks the spatial precision of fMRI. Future studies could benefit from longitudinal designs that track changes in cognitive control as language proficiency evolves or declines, particularly in aging populations.

In addition, including qualitative measures such as language switching behavior or real-life usage patterns could deepen our understanding of how bilingual experience shapes cognition beyond standardized proficiency tests.

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In summary, this study provides robust behavioral and neurocognitive evidence that high bilingual proficiency enhances cognitive control mechanisms. The findings reinforce the view that not all bilingual experiences are equal in their cognitive consequences. High proficiency, active use, and cognitive engagement with both languages appear essential in producing the well-documented bilingual advantage in executive functioning

**Conclusion**

This study explored how second language (L2) proficiency levels influence cognitive control in bilingual individuals, integrating behavioral data and neuroimaging evidence. The findings clearly demonstrate that high-proficiency bilinguals outperform low-proficiency bilinguals in tasks requiring executive functions such as inhibition, task switching, and conflict monitoring. These behavioral advantages were mirrored by increased neural activation in the dorsolateral prefrontal cortex and anterior cingulate cortex—key regions involved in cognitive control.

Importantly, the results affirm that bilingual cognitive advantages are not uniform but are strongly modulated by language proficiency and possibly by the depth of bilingual language engagement. High proficiency likely fosters greater neural efficiency and flexibility, suggesting a use-dependent relationship between bilingualism and executive function.

These findings carry implications for education, clinical practice, and cognitive aging research. Encouraging active bilingualism—especially at high proficiency levels—could support cognitive resilience across the lifespan.

Future studies should further investigate the role of age of acquisition, immersive environments, and bilingual language use in everyday life to refine our understanding of how bilingualism shapes the mind and brain

**Recommendations**

**Promote Bilingual Education Programs**

Given the cognitive advantages associated with higher levels of bilingual proficiency, it is recommended that educational institutions encourage bilingual education from an early age. This can support the development of both language skills and executive functions, fostering cognitive flexibility and enhanced problem-solving abilities in students. Additionally, bilingual programs should aim for balanced bilingualism, as proficiency in both languages appears to be crucial for maximizing cognitive benefits.

**Increase Immersive Language Environments**

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For individuals learning a second language, exposure to real-life, immersive environments is key to achieving high proficiency. Programs that encourage active use of both languages in daily contexts, such as through community language exchanges or study abroad programs, can help learners improve their language proficiency and consequently their cognitive control skills. Language immersion can also reduce the cognitive load typically associated with lower proficiency.

**Focus on Lifelong Bilingualism**

Since bilingualism provides cognitive advantages that may contribute to cognitive reserve and delay the onset of age-related cognitive decline, it is recommended that bilingualism be encouraged throughout adulthood. Even later in life, individuals who have not yet achieved high proficiency in a second language should be supported in language learning initiatives aimed at enhancing cognitive flexibility and protecting against neurodegenerative diseases. Adult education programs focusing on language learning should be made widely accessible.

**Design Cognitive Training Programs for Bilinguals**

Cognitive training interventions could be developed that leverage bilingualism to further enhance cognitive control. These programs should specifically target executive functions such as inhibition, task-switching, and cognitive flexibility, and could be used in various settings including schools, workplaces, and senior centers. Such programs could use bilingual tasks to help participants strengthen their control over cognitive resources, improving both mental agility and language skills

**Further Research on Cognitive Control and Bilingualism**

Given the preliminary nature of this study and the diversity of bilingual experiences, further research is needed to explore how contextual factors (e.g., frequency of language use, cultural background, and age of acquisition) modulate cognitive control. Longitudinal studies tracking changes in cognitive control across the lifespan of bilinguals could provide valuable insights into the long-term benefits of bilingualism. Research into multilingualism and its impact on cognitive control could also yield further insights, especially as the world becomes more interconnected and multilingualism increases.

**Addressing Individual Differences in Proficiency**

Since language proficiency varies widely among bilinguals, it is essential that future studies and programs consider individual differences in proficiency when evaluating bilingual advantages in cognitive control. Tailoring language learning strategies based on a person's proficiency level,

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language context, and cognitive needs can maximize the benefits of bilingualism, ensuring that all learners—whether at high or low proficiency levels—are supported in their cognitive development.

**conflict of interest**

The author declare no conflict of interest

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