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The Effect of Linguistic Code-switching on Cognitive Inhibition in Bilingualism: Evidence from Stroop Tests

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Abstract: Linguistic code-switching is a common phenomenon among bilinguals that requires extensive executive control to manage two languages. However, limited research has specifically examined whether frequent code-switching enhances cognitive inhibition as measured by the Stroop test. Understanding this relationship has important implications for harnessing bilingual advantages in inhibition and executive functioning. Therefore, this study aimed to investigate whether bilingual adolescents who engage in code-switching demonstrate improved cognitive inhibition compared to monolingual peers. Participants were 81 Chinese-English bilinguals aged 14-18, who were assigned to English reading, Chinese reading, or mixed language reading groups. Participants then completed Stroop tests. Results revealed the mixed language group had significantly faster response times on incongruent Stroop trials compared to both monolingual groups, indicating enhanced cognitive inhibition from code-switching. No significant difference emerged between the English and Chinese groups, implying monolingual reading in either language does not differentially impact inhibition.

Keywords: bilingualism, linguistic code switching, executive function, inhibition, stroop test

1. Introduction

Linguistic code-switching, defined as the process of alternating or combining two languages, is a common phenomenon among bilingual speakers, which make up over 50% of the global population [1]. Thus, this concept is of great significance to explore, as the prevalence of code-switching implicates critical topics beyond just language, including individual cognitive styles, interpersonal communication, and even cross-cultural exchange. The process of switching between languages is accompanied with potential cognitive effects on one's executive function, which includes the mental processes of inhibition, working memory, and organizing techniques required to formulate a response [2].

This research focuses specifically on the implication of linguistic code-switching on cognitive inhibition, which is the mind's capacity to filter out stimuli that are unrelated to the task. Supposedly, involving in language-switching activities will bolster cognitive inhibition as managing two languages places extensive demands on executive control abilities [3]. To transition between languages at opportune moments by activating the target language and inhibiting the non-target one, bilinguals must constantly listen to their speech to prevent interruptions from the unwanted

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language.The cognitive inhibition activated by doing the language switching task can potentially transfer to other conflict tasks like the Stroop, which is the task adapted in this research. Understanding the cognitive impact of language switching on one's cognitive inhibition has important real-world implications, such as providing practical strategies bilinguals can use to promote mental fitness and delay age-related cognitive decline. On top of that, linguistic code-switching can serve as a potential approach for bilinguals to overcome distractions, focus attention, multitask, and boost efficiency in everyday life.

A vast amount of research has shown robust positive correlations between bilingual language acquisition and cognitive control over their attention and inhibition among preschool children. Zelazo compared the monolingual preschool children's attention inhibition ability with that of bilingual preschool children by asking them to complete the Dimensional Change Card Sort task [4, 5]. The children received cards that varied on two attributes-color and shape. For illustration, certain cards might be red while others are pink. Those same cards also differ in visual representation, like cat or rabbit. Initially, the children were instructed to categorize the cards by color. After completing the first sorting task, participants are then instructed to re-sort the same set of cards using the other category - shape - as the organizing principle. The result reveals that bilingual participants performed significantly better at task switching than monolingual participants at a young age. That is, they have higher inhibited attention inhibition to color in order to successfully sort by the new category of shape. The present study seeks to build on prior work by examining if engagement in behaviors that require alternating between two languages can further enhance cognitive inhibition skills in bilingual individuals. On top of that, this research differs from Zelazo's research as it focuses more on adolescents than preschool children [4].

Previous research also looked at the relationships between one's daily language switching frequency and executive function abilities among late bilinguals [5]. The study found that bilinguals who regularly switched between languages in daily life demonstrated superior performance on executive control measurements from the flanker and Simon tasks compared to both unbalanced bilinguals and balanced bilinguals who did not frequently switch languages. Meanwhile, no significant differences emerged in task performance between unbalanced bilinguals and balanced non-switching bilinguals. These findings point to frequent, real-world language-switching experience as the key driver of bilingual advantages in cognitive control processes that manage interference resolution. High second language proficiency alone does not appear sufficient to confer the same degree of benefit. Therefore, this study's result is congruent with the current research's hypothesis. However, we conduct the experiment with a different approach by testing participants' cognitive inhibition ability using Stroop test. Besides, the participants in Verreyt's study all had Dutch as their native language and French as their second learned language.; Their results of bilinguals' higher executive function can then be affected by certain linguistic traits of Dutch and French [5]. To eradicate this possibility, this research includes participants with Chinese and English as their first and second languages, which can consolidate the previous research finding by broadening the language barriers.

1.1. Neurological Approach

Examining the neural correlates of code-switching, bilingualism, and executive function is critical for developing a more complete understanding of how these factors interrelate. Stocco put forth the idea that the bilingual experience may lead to the development of a gating system within the striatum. This gating system could dynamically regulate the flow of information to the prefrontal cortex, a brain region implicated in cognitive control. [6]. Besides, a structural MRI study shows that bilingualism is associated with increased gray matter volume in frontal, parietal and temporal regions among adults, which is involved in cognitive control and language processing [7]. The

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current study does not focus on investigating the neurobiological mechanisms, yet the research logistics are congruent with these neurological findings of the brain.

1.2. Current Study

The goal of this study is to explore the relationship between code-switching and cognitive inhibition in bilingual individuals. This will be accomplished by analyzing data from the Stroop test to determine the impact of alternating between languages on inhibitory control. Prior study has shown that bilinguals have better attention inhibition compared to monolinguals and that bilingual individuals who regularly switch between languages on a daily basis tend to exhibit enhanced executive function, as evidenced by superior performance on cognitive tests that assess abilities like attentional control and conflict resolution. This has been demonstrated through results of the Flanker and Simon tasks. However, no study has specifically examined how language code-switching frequency affects cognitive inhibition as measured by the Stroop test in an adolescent bilingual population. Therefore, this study recruits adolescent Chinese-English bilinguals and divides them into linguistic code-switching and non-switching groups and compares their performance on Stroop tests. The unique aspects of this study are the focus on the Stroop test as an outcome measure, the recruitment of Chinese-English bilinguals as participants, and the examination of language-switching in adolescents specifically.

1.3. Hypothesis

According to the literature review, it is hypothesized that bilinguals in the language-switching group which engage in linguistic code-switching will demonstrate enhanced cognitive inhibition and executive control compared to monolingual peers, as evidenced by shorter reaction times on the incompatible condition of the Stroop color-word interference test (Hypothesis 1).

It is also hypothesized that the Stroop test scores of monolingual reading groups (Chinese and English) will not differ significantly since no linguistic code-switching was used to activate the cognitive inhibition function beforehand (Hypothesis 2). However, differences between these two groups can still occur due to participants' different language proficiency levels (Hypothesis 3).

2. Methodology

2.1. Participants

This study involved 81 participants (41 females, 40 males) aged 14 to 18 (Median age = 17, SD = 2.50). The participants in the study consisted of individuals who were bilingual or multilingual. While they possessed proficiency in English and Chinese (either Mandarin or Cantonese), their language dominance profiles varied. Of the total sample, 37 participants had Chinese as their primary language, 24 had English as their primary language, and 20 considered both English and Chinese as their primary languages. The participant pool was diverse, with the individuals coming from a range of backgrounds.

2.2. Materials

Before participants began the study, they had to fill out a self-report language proficiency test via Google Forms. For the reading comprehension task, the experiment utilized the passage "Psychological, Social, and Biological Foundations of Behavior" as reading material and translated the passage to both simplified and traditional Chinese to accommodate those who were literate exclusively on one or the other. To perform the Stroop task, the researcher utilized a computer to

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display the individual columns to the participants and an iPhone timer to record the time that it took for the participants to carry out the procedures. The results from each trial were then tracked on a Google Sheet.

2.3. Measurement

2.3.1. Self-reported Language Proficiency Test

The questions in the self-reported language proficiency survey were adapted from the Language Experience and Proficiency Questionnaire (LEAP-Q) [8], which included 4 multiple-choice questions, 2 short-answer questions and 16 Likert scale rating questions on a scale of 1 to 10. The survey was constructed such that it reflected participants' background information, the first and second language used, as well as the participants' confidence level, proficiency, and learning approaches for English and Chinese. The instructions and questionnaires were distributed to the participants online and were completed at least a few hours before the reading comprehension task and the Stroop task.

2.3.2. Stroop Task

Stroop Task was used in the research as a measurement of cognitive inhibition. In this test, participants were required to identify the color of the words in a column without reading the words as quickly and accurately as they could. There were three columns provided, the "control," the "compatible," and the "incompatible" [9, 10]. In the control column, the meanings of words were neutral and were not related to the colors. On the other hand, the compatible column included words that correspond directly with the colors, such as having the word "red" be red. Finally, the incompatible group were presented with words that were incongruent with their colors. For example, the incompatible group had color words like "red" or "blue" written in color yellow. As the participants read, they are timed on the total amount of time in seconds that it takes for them to correctly list the color of each of the words for the three columns (Figure 1). The average amount of time taken for them to finish the incompatible task was subtracted from that of the compatible task to calculate the final "Stroop Score," which was used in the findings.

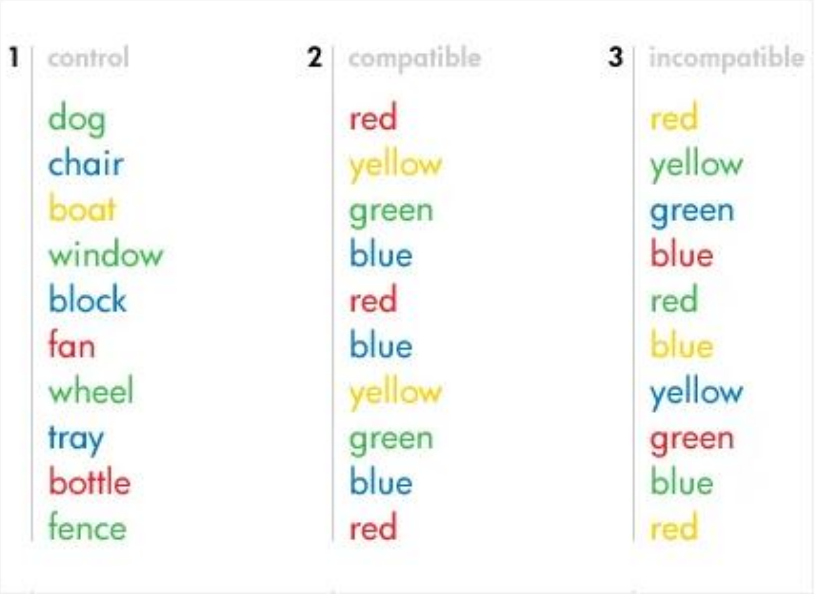

Figure 1: Stroop task columns provided individually to the participants.

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2.4. Procedure

All participants were required to complete a Google form survey concerning their proficiency and acquisition of Chinese and English before engaging in the reading and Stroop tasks in-person or via Zoom.

After completing the survey, participants were then randomly assigned to three different groups for the reading tasks. The first group read a scientific passage in English, the second group read the same passage but in Chinese (both simplified or traditional characters were offered), and the third group read a mixed-language passage in which the first and third paragraphs were in English, while the second and fourth paragraphs were translated to Chinese. The participants were told that they had given a maximum of 3 minutes to read the 4-paragraph passage and asked to summarize each paragraph verbally in its given language to ensure the participants had fully engaged with the passage.

Once the participants had finished summarizing their given passage, they were seated across from an examiner and a computer to conduct the Stroop test. On the computer, they are shown the control column and asked to identify the colors in the column as quickly as possible. When the reader finished, the timer was stopped, and the number of seconds taken for the reader to finish was recorded. This same process was repeated for the compatible and incompatible columns, respectively.

3. Results

After conducting the experiment on participants, the values of the individual Stroop Scores were determined by subtracting the participants' time taken to complete the compatible section of the Stroop Task from the time taken to complete the incompatible section of the Stroop Task. A lower Stroop Score indicated a faster response time. When the researcher compared the average Stroop Scores of the English, Chinese, and Bilingual reading groups, the results demonstrated that the bilingual reading groups, with a mean Stroop Score of 1.46, had faster response times than did the monolingual reading groups (Chinese: 3.34, English: 3.02).

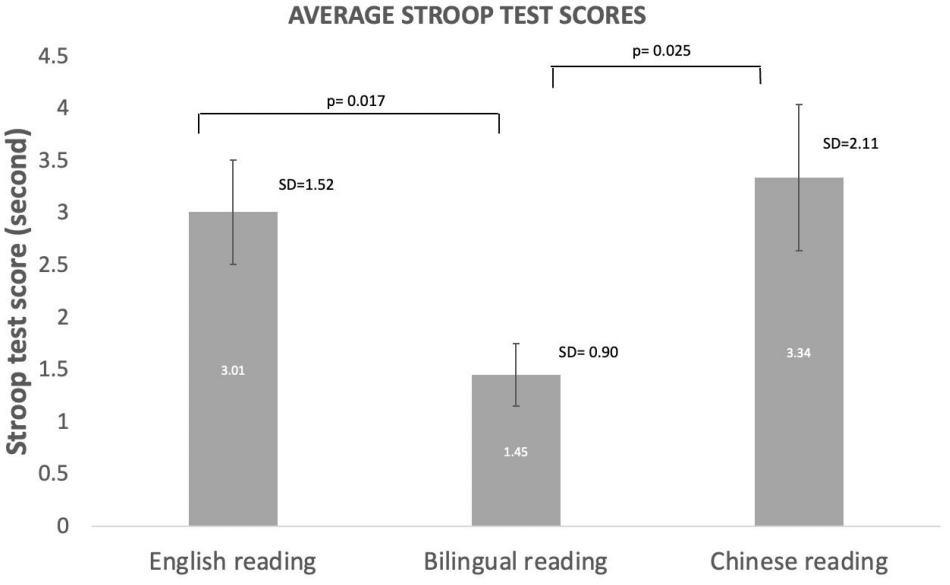

Figure 2: Results of stroop tests for three groups.

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Figure 2 was constructed to illustrate the calculated mean average Stroop Scores among three different test groups–English, Bilingual, and Chinese. The average score for bilingual reading participants, 1.45 seconds, was 1.56 seconds less than the average score of the English reading group and 1.89 seconds less than the times of the Chinese reading group. According to the T-test, the average Stroop score of the English reading group is significantly higher than the bilingual reading group with a p value of 0.017; the average score of the Chinese reading group was less yet also significantly higher than the bilingual group with a p value of 0.025. Thus, the result was consistent with the researcher's hypothesis that engaging in linguistic code-switching activities bolstered cognitive inhibition, as managing two languages placed extensive demands on executive functioning abilities.

When the English and Chinese reading groups were compared, they had a p value of 0.71, which demonstrated an insignificant difference in Stroop test performance between the two monolingual groups. This statistically insignificant difference suggests that there was less of a difference in the recruitment and utilization of cognitive inhibition and associated brain regions between the English and Chinese monolingual reading groups compared to the difference observed between the monolingual and bilingual reading groups. In other words, the monolingual English and monolingual Chinese participants exhibited more similar levels of inhibitory control, as evidenced by their Stroop test results, while bilingual code-switchers displayed enhanced cognitive inhibition compared to both monolingual groups. The insignificant difference between the two monolingual groups aligns with the study's prediction that frequent engagement in code-switching provides specific benefits to inhibitory control beyond those attained through monolingual reading alone. The comparable Stroop interference effects seen in both monolingual groups imply that the act of reading in one language versus another language does not differentially impact inhibitory processing. Rather, actively managing two linguistic systems through code-switching appears to strengthen cognitive inhibition skills selectively.

4. Discussion

The results indicated that Chinese-English bilinguals who actively engaged in language-switching tasks demonstrated enhanced cognitive inhibition compared to monolingual peers, as evidenced by shorter reaction times on the incongruent tasks of the Stroop task. This is consistent with earlier research that claimed bilinguals' executive function is put under more stress and their cognitive control is strengthened by the constant requirement to manage and transition between two languages [11, 12].

However, there are a few notable limitations. First, the relatively small sample size of 27 participants per group provides limited statistical power. Testing these effects in a larger cohort would improve generalizability. Second, the narrow age range of 14-18 years old may restrict conclusions to a specific developmental stage, as prior studies have indicated that executive function efficiency generally declines with older age [13-15]. Third, this study exclusively used the Stroop test rather than a variety of executive function assessments. Incorporating these additional cognitive measures could provide a more robust characterization of the bilingual inhibitory control advantage. Fourth, self-reported language proficiency could be vulnerable to subjectivity. To minimize this, subsequent studies should utilize formal language assessments to strengthen proficiency classification. Finally, the cross-sectional design only examines code-switching effects at one point in time. Longitudinal tracking could better establish causal relationships between code-switching and enhanced cognitive control.

Despite these limitations, this study also had notable strengths. The inclusion of both the Chinese and English monolingual control groups and a bilingual code-switching group allowed for the isolation of the impact of linguistic code-switching rather than using the second language alone.

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Additionally, the use of the widely validated Stroop test as a relevant measure of cognitive inhibition provided strong grounds for linking language control processes and executive function.

Moving forward, several promising directions exist for further research in this area. Firstly, future studies can examine the effects of different code-switching patterns, including the comparison between one-way and two-way switching, single-word and whole-sentence switching, and the role of switching frequency. These studies can also be extended on a neurobiological approach by investigating brain activation during code-switching using fMRI or EEG methods. Conducting longitudinal studies to track bilingual participants over time would also allow for stronger conclusions about the causal relationships between code-switching, language proficiency, and cognitive gains. Furthermore, real-world outcomes of linguistic code-switching can be investigated, like academic grades, standardized test scores, or other cognitive assessments that could reveal more practical, real-world significance. Lastly, more extensive age ranges can be included in future studies. That way, researchers can compare the effects of code-switching on cognitive inhibition in children, younger adults, and elderly populations and uncover insights into maximizing bilingual advantages across the lifespan.

5. Conclusion

In conclusion, this study provided initial experimental evidence that frequent code-switching may improve inhibitory control in bilingual participants. While future research is needed to address methodological limitations, these findings contribute to a growing understanding of the cognitive implications of navigating a bilingual environment. This work helps characterize code-switching as a potential asset for bilingual youth that could be leveraged in educational settings to maximize cognitive and academic outcomes.

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