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The Impact of Language Quantity and Usage Balance on Inhibitory Control: An ERP Study

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Abstract

This pilot study investigates the influence of linguistic diversity, specifically the number of languages spoken (bilinguals vs. trilinguals) and the degree of language balance (balanced vs. unbalanced), on inhibitory control. The study recruits 10 participants, categorized into four groups based on their linguistic profiles: balanced bilinguals, unbalanced bilinguals, balanced trilinguals, and unbalanced trilinguals. Inhibitory Control was assessed using classic Eriksen Flanker Task.

Our analysis revealed no significant differences in inhibitory control between bilinguals and trilinguals. Similarly, no significant advantages were found for balanced language users over unbalanced ones in terms of inhibitory control. These findings may be attributed to limitations in sample size and experimental design. Future studies are planned to address these issues and further explore the complexities of how multilingualism affects cognitive functions.

These findings contribute to the understanding of cognitive advantages associated with multilingualism and underscore the importance of language balance in leveraging these benefits. The results advocate for further investigation into the mechanisms linking linguistic diversity and cognitive performance, with implications for educational strategies and cognitive development in multilingual contexts.

Keywords: executive function, inhibitory control, bilingualism, trilingualism, Eriksen Flanker Task

Introduction

Inhibitory Control

Executive functions broadly encompass a set of higher cognitive processes, including cognitive shifting, working memory, and inhibitory control as key components(Prencipe et al., 2011). In a narrower sense, executive functions specifically refer to inhibitory control, which is the ability to suppress responses to irrelevant stimuli while pursuing cognitive representations of goals.

The most classic cognitive tasks for measuring inhibitory functions currently include the Simon task (Simon & Rudell, 1967), the Stroop task(Stroop, 1992), and the Eriksen Flanker task(Eriksen & Eriksen, 1974). The Simon task is primarily used to measure the spatial stimulus-response congruence effect, assessing how individuals deal with stimuli that appear in unexpected locations. In this task, if a stimulus appears on one side of the screen, participants are required to quickly press a button on the opposite side. The Stroop task is also used to measure an individual's ability to process interfering information. Participants are asked to name the color of the print, not the meaning of the word itself. For example, the correct response to the word ‘red’ printed in blue would be ‘blue’. The Flanker task is another psychological measure used to assess attention and inhibitory control. Participants must focus on a target stimulus in the center of the screen while ignoring adjacent distractors. These distractors may be congruent (e.g., all arrows pointing left) or conflicting (e.g., a central arrow pointing left with flanking arrows pointing right). The participant's task is to respond quickly according to the direction of the central arrow. The Flanker task not only tests participants' response speed but also their ability to inhibit distracting stimuli, making it widely used in studies of attention control and executive functions.

Inhibitory Function Between Monolinguals and Bilinguals

Numerous studies have shown that bilinguals possess enhanced inhibitory control compared to monolinguals (Bialystok et al., 2005; Martin-Rhee & Bialystok, 2008). A possible explanation is that bilinguals frequently switch between two languages. To smoothly output one language, they must continually suppress conflicting information from the language they are not using now. This constant process of selection and suppression strengthens the brain's executive control functions, especially inhibitory control abilities. However, some studies did not find this bilingual advantage in inhibitory control (Paap & Greenberg, 2013; Paap et al., 2015). The results may be associated with the diversity of speakers' linguistic profiles and experiences. Depending on their life experience, one bilingual speaker can differ from another in many ways. Such heterogeneity in linguistic experiences has been shown to have led to diverse cognitive consequences, such as level of language proficiency (Mishra, Hilchey, Singh, & Klein, 2012), stage of second language acquisition (Kalia, Wilbourn, & Ghio, 2014), the degree of bilingualism (Goral, Campanelli, & Spiro, 2015), pattern of language use, varying experience with frequent language switch (Soveri, Rodriguez-Fornells, & Laine, 2011), the similarity between a bilingual speakers' two languages (Coderre & van Heuven, 2014) and multilingualism (Poarch & van Hell, 2012) .

Inhibitory Function Between Bilinguals and Trilinguals

Recently some studies have expanded research from monolinguals and bilinguals to trilinguals and multilinguals, further comparing their inhibitory control. Poarch and van Hell

(2012) show no significant difference in inhibitory control between bilinguals and trilinguals. They used the Simon tasks to measure inhibitory control and found that monolinguals were slower compared to bilinguals and trilinguals, suggesting that bilinguals and trilinguals performed better in inhibitory control than monolinguals. This was supported by similar research with younger participants (Poarch & Bialystok, 2015; Vega-Mendoza, West, Sorace, & Bak, 2015).

However, some other studies suggest differences in inhibitory functions between bilinguals and trilinguals. Madrazo & Bernardo (2018) evaluated Filipino-English bilinguals and Cebuano-Filipino-English trilinguals in the Philippines on language proficiency and performance in the Simon Arrows task. They observed a trilingual advantage in complex cognitive tasks but not in simple tasks requiring only response inhibition.

Behavioral Research Question

Previous research on executive functions (specifically inhibitory control) is plentiful for monolinguals and bilinguals, but scarce for trilinguals. In addition, most studies don’t use very precise measures for the degree of bilingualism or trilingualism. Specifically, participants categorized as trilinguals may not be proficient in their third language, especially younger participants whose experience with the third language might be very limited. Furthermore, factors related to proficiency, such as age of acquisition, language switching experience, and language balance, are crucial for enhancing the inhibitory control of bilinguals, making it important to categorize trilinguals more finely.

Therefore, our pilot study refines the criteria for measuring multilingual users, aiming to explore how linguistic diversity (bilingual/trilingual) and usage balance (balanced/unbalanced) affect the inhibitory function of bilinguals and trilinguals, from a behavioral level.

We have 2 behavioral hypotheses: H_1: Balanced trilinguals have better inhibitory control than balanced bilinguals; H_2: Balanced bilinguals have better inhibitory control than unbalanced trilinguals (interaction effect).

Neural Research Question

Besides, in order to better explore the neural mechanism behind the inhibitory control of multilingualism, we combine our behavioral experiment with EEG.The inhibitory control involves being able to control one's attention, behavior, thoughts, and emotions to override a strong internal predisposition or external lure, and instead, do what's more appropriate or needed(Diamond, 2013). Here, we are going to use the Eriksen Flanker Task combined with EEG to test the inhibitory control ability between different groups. In the Eriksen flanker task, inhibitory control involves the following EEG components:

N1 Component

The N1 component is a negative component that appears approximately 100ms in the occipital, parietal, central, and frontal electrode sites. It is considered an index of early attentional processing, with larger N1 amplitudes signifying better attentional processing(Dong & Zhong, 2017). So people with better inhibitory control will have larger N1 amplitude.

P2 Component

The P2 component is an early positive deflection that occurs between 150 to 275 ms post-stimulus onset and indexes selective attention or change detection(Chung-Fat-Yim et al., 2021), people with better inhibitory control have earlier and smaller P2.

N2 Component

The N2 component is a fronto-central negative deflection that peaks at around 200-300 ms after stimulus onset. A larger N2 amplitude has been associated with enhanced conflict monitoring and signaling for stronger cognitive control(Markiewicz et al., 2023). People with better inhibitory control will have earlier and higher N2.

P3 Component

The P3 component. is a positive component with centro-parietal distribution and is associated with attentional resource allocation during stimulus categorization. Shorter P3 latencies are associated with shorter stimulus evaluation, and larger amplitudes are proportional to the amount of attentional resources allocated to stimulus processing.

So people with better inhibitory control will have earlier and smaller p3 (Markiewicz et al., 2023).

Error-related Negativity Component

Error-related negativity(ERN) component is a neural response that reflects error monitoring(Lawler et al., 2021). People with better inhibitory control will have larger ERN amplitude.

So from the above information and behavioral hypothesis, we propose the following neural hypothesis:

H_3: balanced trilinguals will have larger N1 amplitude than balanced bilinguals than unbalanced trilinguals.

H_4: balanced trilinguals will have smaller and earlier P2 than balanced bilinguals than unbalanced trilinguals.

H_5: balanced trilinguals will have larger and earlier N2 than balanced bilinguals than unbalanced trilinguals.

H_6: balanced trilinguals will have smaller and earlier P300 than balanced bilinguals than unbalanced trilinguals.

H_7: balanced trilinguals will have larger ERN component amplitude than balanced bilinguals than unbalanced trilinguals.

Methods

Participants

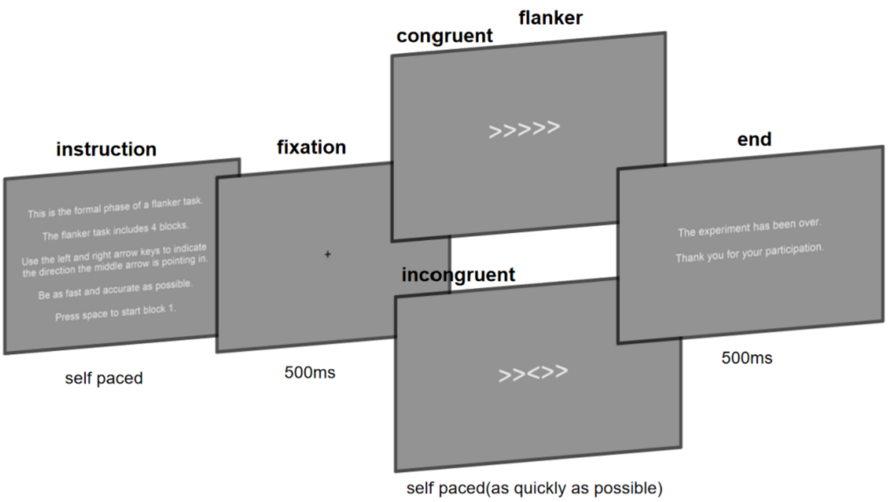
In order to better define the number of languages mastered, the level of proficiency, and the balance. We measured the number of languages mastered by the subjects based on their language education experience and objective language test scores. Their proficiency in each language was then measured according to the Common European Framework of Reference for Languages(Division, 2001). For the operational definition of balance, we used the balance in the proficiency of the different languages mastered by the subjects(Poarch & Bialystok, 2015), through which we measured each subject's proficiency in different languages by applying statistical methods to measure whether they are balanced multilingualism. We made the above information into a questionnaire (see Supplementary Table), and after the screening, we finally recruited 10 subjects (one male, Mage = 24.80， SDage = 2.82), which contained 2 Balanced bilinguals, 3 unbalanced bilinguals, 2 balanced trilinguals, and 3 unbalanced trilinguals.

Task

The Eriksen Flanker Task(see Figure 1) was designed to assess the inhibitory control of subjects. At the beginning of the task, subjects were required to focus their attention on a fixation in the center of the screen for 500 milliseconds. Subsequently, subjects were required to react as quickly as possible to the flanker that appeared in the center of the screen, judging its orientation. The flankers consist of two types: congruent and incongruent, and their ratio was 4:1. Throughout the experiment, the presentation of the stimuli was randomized. Before the formal experiment, subjects will be instructed to perform an exercise consisting of one block including 10 trails, with a 4:1 ratio of congruent to incongruent, consistent with the formal experiment. During the exercise, subjects' responses will be recorded by the computer and timely feedback will be given as "correct or incorrect" to help subjects understand the rules of the task. At the end of the exercise and after understanding the rules, the subjects were allowed to proceed to the formal experiment. The formal experiment consisted of 4 blocks, each containing 30 trials. Between every two blocks, subjects were allowed to take a one-minute break to relax and adjust their attention.

Figure 1

Flanker task



Data analysis

Descriptive statistics were conducted on the questionnaire data. Individual self-assessment scores for listening, speaking, reading, and writing in each language were standardized to obtain z-scores. The independent sample T-test was performed, yielding significant results. Before deeper analysis, we removed one outlier. We checked congruency on the Flanker task, which also produced significant results. Repeated measures ANOVA was applied to both accuracy rates and reaction times.

Results

Balanced and Unbalanced Groups

Initially, participants' self-assessed language proficiency scores were normalized. Based on the differences in self-assessed proficiency standardization Z score across their languages, participants were categorized into either a balanced or unbalanced group. For bilinguals, according to the difference between L1 and L2, there is a significance between balanced bilinguals and unbalanced bilinguals ($t(3) = -4.19$, $p = .025$). For trilinguals, according to the difference between L1 and L3, there is a significance between balanced trilinguals and unbalanced trilinguals ($t(3) = -4.38$, $p = .022$).

Table 1.

The independent sample T-test between balanced bilinguals and unbalanced bilinguals

△1	statistic	*p*	Cohen's d
	-4.19	0.025	-3.83

Note: △1 means the difference between L1 and L2.

Table 2.

The independent sample T-test between balanced trilinguals and unbalanced trilinguals

△2	statistic	*p*	Cohen's d
	-4.38	0.022	-3.89

Note:△2 means the difference between L1 and L3,

Bilingual participants were categorized into balanced and unbalanced based on the disparity between their first and second languages. Similarly, trilingual participants were divided into balanced and unbalanced groups according to the difference between their first and third languages. The final composition included three unbalanced bilinguals, two balanced bilinguals, three unbalanced trilinguals, and two balanced trilinguals.

Flanker task

Descriptives and congruency

For all participants, there are descriptives on Flanker task. For accuracy, there is a significance between balanced bilinguals and unbalanced bilinguals ($t(8) = 3.96$, $p = .004$). For reaction time, there is a significance between balanced trilinguals and unbalanced trilinguals ($t(8) = -9.72$, $p < .001$).

Table 3.

Accuracy and reaction time in congruency and incongruency condictions

	Con-acc	Con-rt	Incon-acc	Incon-rt	Accuracy	RT
M	0.980	0.371	0.819	0.437	0.945	0.384
SD	0.023	0.025	0.140	0.043	0.050	0.028

Table 4.

The paired samples T-test between congruency and incongruency condition

	statistic	*p*	Cohen's d
Accuracy	3.96	0.004	1.32
RT	-9.72	< 0.001	-3.24

Accuracy

With accuracy as the dependent variable, the main effect of congruency was significant, $F(1, 5) = 8.23$, $p = .035$, $\eta 2p = 0.622$, but the main effect of language and balance was not significant. Post hoc analysis found that there is significant difference between congruency condition and incongruency condition ($t (5) = 2.87$, $p = .035$).

Table 5.

Results of Repeated measures ANOVA in accuracy

	F	*p*	η^2_p
Congruency	8.231	0.035	0.622
Language	0.100	0.765	0.200
Balance	0.653	0.456	0.116
Language*Balance	0.127	0.736	0.025
Congruency*Balance	0.303	0.606	0.057
Congruency*Language	0.152	0.713	0.029
Congruency*Language*Balance	0.114	0.750	0.022

Reaction time

With reaction time as the dependent variable, repeated measures ANOVA showed significant main effect of congruency, $F(1, 5) = 173.68$, $p < .001$, $\eta 2p = 0.972$, and significant interaction effect of congruency and balance, $F(1, 5) = 9.81$, $p = .026$, $\eta 2p = 0.662$, but the main effect of language and balance was not significant. Post hoc analysis found that there is no significant difference in the balance group and the unbalanced group in the congruency condition, but in the incongruency condition, the balanced group was significantly higher than the unbalanced group ($t\ (5) = 2.59$, $p = .049$).

Table 6.

Results of Repeated measures ANOVA in reaction time

	F	*p*	η^2_p
Congruency	173.680	< 0.001	0.972
Language	0.008	0.934	0.002
Balance	5.541	0.065	0.526
Language*Balance	1.002	0363	0.167
Congruency*Balance	9.809	0.026	0.662
Congruency*Language	0.204	0.670	0.039

Discussion

For one thing, there is no significant difference in inhibitory control between bilinguals and trilinguals. The result is consistent with previous studies (Poarch & van Hell, 2012). Indeed, most researchers consider trilingualism as a variant of bilingualism and they use models of the second language acquisition to characterize the process of acquiring trilingualism (Chevalier, 2015). Therefore, for bilinguals and trilinguals, they appear to have similar level of inhibitory control. For another, we did not get the result that participants with balanced language proficiency have better inhibitory functions compared to those with unbalanced language proficiency. This may have something to do with our experimental design and relatively small sample size.

Therefore, in our future work, we will carry out our work in the following aspects: (1) Small sample size makes it difficult to achieve an adequate effect size so that we need to increase the number of participants later; (2) In the pilot study we use a non-semantic Flanker Task. Its stimulus are arrows, which do not involve any lexical or conceptual relationships. In contrast, semantic-related flanker tasks require participants to process conflicts among semantic information, which may be more closely associated with the number of languages a participant speaks, as well as their proficiency and balance in those languages; (3) Instead of self-report scales, we should employ more precise tasks of language ability such as Oxford Online Placement Test; (4) In the pilot study there is no maximum reaction time setting in Psychopy. And During data processing, we observed that longer reaction times were associated with higher accuracy rates. This suggests that many participants adopted a cautious approach to ensure accuracy, rather than responding both quickly and accurately as instructed. Therefore, one solution is to Establish a time threshold: taking too long to respond is automatically counted as incorrect; (5) Due to time and equipment limitations, we conducted only behavioral experiments at this stage. Future research is planned to incorporate electroencephalography (EEG) studies to further explore the topic.

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Supplementary Table

亲爱的同学：

您好！非常感谢您能抽出宝贵的时间参与本次调查，该调查的目的在于了解当代高校大学生语言学习情况。您的回答无对错之分，根据自身实际情况做出合适的选择即可。我们保证对您的个人信息进行严格保密，调查结果仅作科学研究使用。最后，衷心感谢您的支持与合作！祝学业顺利，生活愉快！

1、你的性别：男□ 女□

2、你的年龄为_________周岁

3、你就读的专业为_________

4、你掌握的外语包括（可多选）:英语□ 法语□ 葡萄牙语□ 日语□ 其他__

____

5、你是否考过大学生英语六级考试：否□ 是□_____分

6、你是否考过英语专业四级考试：否□ 是□____分

7、你是否考过英语专业八级考试：否□ 是□____分

8、你是否考过托福：否□ 是□_____________分

9、你是否考过雅思：否□ 是□_____________分

10、你是否考过除英语以外的其它语言能力测试：

否□ 是□ [请在横线处说明是哪一种语言的哪一种测试，并写明测验分数/等级]

____

11、请你根据对自己中文听说读写四个维度的水平的感知，选择 1—7所相应的选项。数字越大代表你的水平就越高。请参考附录部分的说明，进行勾选。

听	○1	○2	○3	○4	○5	○6	○7
说	○1	○2	○3	○4	○5	○6	○7
读	○1	○2	○3	○4	○5	○6	○7

写	○1	○2	○3	○4	○5	○6	○7

12、请你根据对自己**英文**听说读写四个维度的水平的感知，选择 1—7所相应的选项。数字越大代表你的水平就越高。请参考附录部分的说明，进行勾选。

听	○1	○2	○3	○4	○5	○6	○7
说	○1	○2	○3	○4	○5	○6	○7
读	○1	○2	○3	○4	○5	○6	○7
写	○1	○2	○3	○4	○5	○6	○7

13、请你根据对自己**第二外语**听说读写四个维度的水平的感知，选择 1—7所相应的选项。数字越大代表你的水平就越高。请参考附录部分的说明，进行勾选。

听	○1	○2	○3	○4	○5	○6	○7
说	○1	○2	○3	○4	○5	○6	○7
读	○1	○2	○3	○4	○5	○6	○7
写	○1	○2	○3	○4	○5	○6	○7

附录：为了帮助被试更好地理解以上三个自评量表，这里分别对听、说、读、写四维度从1到7点所表示的具体含义作出解释，被试可以结合这些描述来圈出最合适自己实际情况的数字。

一、听力

1点 - 非常基础	能够理解非常熟悉的词汇，如日常问候语，但在理解完整句子或对话时遇到困难。
2点 - 基础理解	能够理解简单的句子和常用短语，如自我介绍和日常购物对话，但不能理解较快的讲话或复杂句子。
3点 - 有限理解	能够跟随缓慢和清晰的语言对话，理解主要内容，尤其是与日常生活相关的话题，但对细节的理解有限。
4点 - 一般理解	能理解标准语速的对话中的大部分内容，包括一些不熟悉的话题，但对隐含意义或复杂表达可能不太敏感。
5点 - 较强理解	能够理解中等速度的对话和讲话，即便是那些涉及较为复杂话题和一些非正式用语的内容。
6点 - 高级理解	能够理解快速、自然的语言交流，包括对话中的隐喻和细微的文化暗示，尽管偶尔会遇到一些理解上的挑战。
7点 - 完全理解	能够无困难地理解该语言的各种听力材料，包括专业讨论、电影对话以及具有不同地域特色和口音的讲话，能够捕捉并理解细节和隐含的复杂信息。

二、口语

1点 - 极为基础	能使用几个简单词汇和短语，比如打招呼或告别，但无法构建完整句子。
2点 - 基础交流	能用简单的句子交流个人信息和日常生活需求，但通常说话缓慢且需经常寻找单词。
3点 - 基本对话	能就熟悉的话题进行简单对话，尽管仍然有限制，并需要对方耐心配合。
4点 - 日常对话	能够进行日常对话，并在熟悉话题上表达自己的想法和意见，但在复杂话题上还需努力。

5点 - 流畅表达	在多数日常和一些专业场合下，能较为流畅地表达自己的观点和感受，尽管偶尔会有犹豫和错误。
6点 - 高级表达	能够在广泛的话题上与母语者流畅沟通，包括一些抽象和复杂的内容，仅在压力下才显示出轻微困难。
7点 - 精通表达	能够在任何正式或非正式场合下自如地使用该语言，表达思想精准且自然，能够适应不同的语境和听众。

三、阅读

1点 - 识字阶段	能识别字词，理解一些基本的词汇如数字、颜色和常见的日常用语，但理解句子和段落困难。
2点 - 初级理解	能理解简单的句子和常见的短语，例如路标、菜单或大型广告牌上的信息。
3点 - 基本理解	能阅读并理解简单的文字材料，如日常生活相关的通知和简单的个人信件。
4点 - 日常阅读	能较好地理解日常生活中使用的文本，如报纸简讯、常规电邮和简短的文章。
5点 - 扩展阅读	能够理解较复杂的文本，如详细说明、故事和一般兴趣的文章，并能把握作者的主要观点。
6点 - 深入理解	能够阅读和分析专业领域的文章，理解复杂论点和抽象概念，并能捕捉文中细微的语气和风格。
7点 - 精通阅读	能够轻松理解该语言下任何类型的材料，包括抽象的、结构复杂的或专业领域的文献，能够批判性地评价文本内容和风格。

四、写作

1点 - 基础标记	能够书写一些基础的字词和短语，如个人姓名和常见的日常用词。
2点 - 简单句子	能写出基本的简单句子，例如自我介绍和日常生活中的需求表达，错误较多。

3点 - 基本段落	能够编写简单的段落，表达个人经历或描述常见事物，语法和句式结构有限。
4点 - 一般性写作	能够写出结构合理的短文，包括叙述和说明文，并能在熟悉的话题上做一定程度的讨论。
5点 - 较为完整的文章	能够撰写内容较为完整、结构清晰的文章，包括个人观点和详细描述，语言上有一定的连贯性和多样性。
6点 - 高级写作	能够写出逻辑性强、内容丰富的论文和报告，能够在文本中使用恰当的连接词，表达清晰，语法错误较少。
7点 - 专业水平	能够自如地进行学术和专业领域的写作，文体多样，语言精确，能够运用高级词汇和复杂句型，准确表达复杂概念和细微情感。