

## 摘要

词汇是习得一门外语的重要前提，在语言使用过程中占据核心地位。然而，我国大学生在词汇学习过程中出现的费时低效、参差不齐等问题至今仍未得到有效改善。词汇的学习与记忆问题已逐渐成为阻碍大多数学习者提高外语学习效率的“瓶颈”。因此，围绕外语词汇学习能力的个体差异问题开展描述、解释及预测性研究显得尤为重要，有助于为今后进一步干预和优化词汇学习效果提供科学依据。文献计量可视化分析结果显示，近十年国内外的词汇习得研究日益呈现出多元化和跨学科的特点，但无论在研究视角、研究方法还是研究内容方面均存在较大的发展空间。

鉴于此，本研究拟围绕外语词汇习得的内在机制及个体差异问题开展多维度、大样本以及可重复的跨学科实验研究。结合具有高时间分辨率特征的脑电技术及多种数据分析方法（如事件相关电位分析、静息态 EEG 分析、机器学习等），深入考察个体在外语词汇学习过程中的大脑活动规律；并以此为基础，试图寻找表征词汇习得深度（是否记住）以及词汇习得广度（记住多少）的关键性脑电指标，构建基于行为和神经科学的外语词汇学能预测模型，以推动我国外语词汇教学实践与研究的发展。为实现上述目标，本研究拟提出以下四个研究问题：

- （1） 成人的外语词汇学习能力差异主要体现在哪些行为（外部）和神经（内部）表现？
- （2） 为什么会出现外语词汇学习能力的个体差异？外语词汇学习能力的个体差异主要与哪些内部因素有关？
- （3） 外语词汇学习过程中的大脑信号变化是什么样的？能否找到预测词汇语义通达的神经指标？
- （4） 不同阶段的大脑神经活动（学习前-静息态、学习中-任务态）能否有效预测个体的外语词汇学习能力？

对上述研究目标及问题的探究主要基于 4 项研究（包含 7 项子研究）。**研究一**主要从行为学角度探讨外语词汇学习能力的个体差异问题。其中，子研究 1 和子研究 2 分别采用 LLAMA 和新型词汇配对联想两种不同的行为实验范式，从不同研究视角揭示外语词汇学能差异的外在表现（**问题 1**）及内部影响因素（**问题 2**）。**研究二**主要围绕外语词汇学习进程开展任务态脑电研究（**问题 3**、**问题 4**）。其中，子研究 3 主要借助 ERPs 技术对外语词汇学习进程的神经活动变化进行分析和总结；子研究 4 则根据最终词汇测试结果，将学习阶段的试次进行分类（正确/错误），并结合跨试次平均以及单试次信号分析（机器学习）等方法，进一步提取预测词汇语义通达的脑电指标。**研究三**计划从静息态脑电分析视角探究词汇学能

的个体差异问题,以期在脱离实验任务的条件下找到预测词汇学习能力的静息态脑电指标(问题4)。其中,子研究5和子研究6将分别从大脑局部(频谱分析)和大脑整体(功能连接分析)角度考察与外语词汇学习能力密切相关的静息态脑电指标。最后,为了进一步验证实验研究结论的可靠性,避免“可重复性危机”,研究四(子研究7)将通过改善实验范式、扩大样本年龄范围等方法,围绕外语词汇习得的神经机制开展验证性脑电研究,以提升研究结论的可靠性及泛化性(问题3)。

研究结果表明:1)(问题1)成人学习者无论在词汇初始学习阶段还是记忆保持阶段,均展现出较大的个体差异。此外,外语词汇学习能力的个体差异在行为和神经层面上的表现形式不同:行为层面主要体现在词汇学习速率和长时记忆效果的差异;神经层面则主要表现为词汇学习所诱发的N400和P600成分的神活动强度不同。2)(问题2)外语词汇学习能力与年龄、工作记忆、长时记忆、注意力和智力之间存在不同强度的相关性;其中,长时记忆和警觉性注意力可以显著预测个体的外语词汇学能水平。这表明外语词汇学习能力不是一个仅与语言学习相关的领域特殊性能力,而是一个与不同认知能力密切相关的领域一般性能力;此外,长时记忆和警觉性注意力的不同可能是导致个体外语词汇学能出现差异的内在成因。3)(问题3)在外语词汇知识构建过程中,大脑不同区域诱发了P200, N400以及P600的学习效应,且这些脑电成分在词汇习得过程中对应的心理活动有可能不同。此外,P600成分是外语词汇语义通达的重要神经标记,在构建词汇语义表征过程中具有重要的参考价值。该结果在重复性脑电实验中已得到进一步论证。4)(问题4)无论是在词汇学习前,还是在词汇学习过程中,我们都分别找到了预测个体词汇学习能力的神经指标。具体而言,任务态下诱发的P600平均波幅和静息态下的alpha频段能量(包括额—枕区域的功能连接强度)均可以显著预测外语词汇学习能力的个体差异。

总体而言,本研究从学习者个体差异的视角切入,按照“描述(现象)—解释(机制)—预测(行为)—验证(结论)”的整体思路对外语词汇学习能力进行了递进式、系统化的研究。本研究无论在研究视角、研究方法还是研究内容上,均有不同程度的创新之处,为揭露外语词汇学能个体差异现象背后的大脑奥秘做出了一定的贡献。

**关键词:** 外语词汇学习能力; 个体差异; 神经机制; 认知能力; 脑电; 可重复性

## Abstract

Vocabulary is an important prerequisite for the acquisition of a foreign language, and it plays an important role in language use. However, the time-consuming, low-efficiency, and disequilibrium problems in the vocabulary learning process among Chinese college students have not been effectively solved so far. Furthermore, vocabulary learning and memorizing has gradually become a “bottleneck” that hinders most learners from improving foreign language learning efficiency. Therefore, it is necessary to carry out a series of descriptive, explanatory and predictive research on the individual differences in foreign word learning ability, which helps to provide scientific evidences for further intervention and optimization of vocabulary learning in the future. The results of bibliometric visualization analysis show that the research on vocabulary acquisition at home and abroad in recent ten years has been increasingly diversified and interdisciplinary in content, but there is still a large room for enrichment in terms of research perspectives, research methods and research content.

In view of the current research situation, we intend to conduct a series of multi-dimensional, reproducible, and interdisciplinary experimental research with large sample, focusing on the internal mechanism of foreign word acquisition and individual differences. In this study, we adopt both the EEG technology with high time resolution and a variety of EEG data analysis methods (such as ERP analysis, resting EEG analysis, machine learning, etc.), with an aim to investigate the individual brain activity patterns in the process of foreign word learning. On this basis, we attempt to find the key EEG indicators representing the depth of vocabulary acquisition (remember or forget) and the breadth of vocabulary acquisition (the quantity of remembered words). Besides, we hope to construct a model predicting the foreign word learning ability based on behavioral and neural markers, which could in turn promote the development of vocabulary teaching practice and research in China. In line with these objectives, this study attempts to address the following four research questions:

- (1) If there are individual differences in adults' foreign word learning ability, then how are they represented at the behavioral (external) and neurological (internal) level?
- (2) Why are there individual differences in foreign word learning ability? Which internal factors are responsible for this phenomenon?
- (3) What are the changes of brain signals in the process of vocabulary learning? Can

we further find the neural marker predicting the lexical semantic access?

- (4) Can neural activities at different stages (pre-learning/resting state OR in-learning/task state) effectively predict the foreign word learning ability?

This research consists of 4 studies, including 7 sub-studies in total. In study 1, the individual differences in foreign word learning ability were investigated from a behavioral perspective. In this study, we have adopted two behavioral paradigms, like the LLAMA task and the adapted word paired-associates task, to reveal the external manifestation (RQ1) and internal factors (RQ2) of word learning differences from different research perspectives. In study 2, the task-based EEG was used to explore the neural representation of foreign word learning process (RQ3/RQ4). In sub-study 3, we have adopted the ERPs analysis on the brain activity changes during word learning. In sub-study 4, the word trials in the learning stage were classified (correct/incorrect) according to the word recall performance, and cross-trial averaging method as well as single-trial analysis (machine learning) were employed to further extract the EEG indicators of lexical semantic access. The 3<sup>rd</sup> study attempted to find the resting-state EEG markers that predict foreign word learning ability without any tasks (RQ4). Specifically, in sub-study 5 and sub-study 6, the resting-state EEG indicators closely related to foreign word learning ability were investigated from the perspective of local brain analysis (spectral analysis) and whole brain analysis (functional connectivity), respectively. Finally, in order to further verify the reliability of the research conclusions and to avoid the “Reproducibility Crisis”, we conducted the 4<sup>th</sup> study (sub-study 7) in which we adapted the experimental paradigm slightly and expanded the age range of samples, so as to improve the reliability and generalization of the research conclusions.

The results of the research are as follows: 1) (RQ1) Adult learners show large individual differences in both the initial vocabulary learning stage and the memory retention stage. In addition, individual differences in foreign word learning ability are represented differently at the behavioral and neural levels. Specifically, at the behavioral level, differences are mainly reflected in the vocabulary learning rate and the long-term memory; while at the neural level, they are mainly manifested in the amplitude of the N400 and P600 components evoked by word learning. 2) (RQ2) foreign word learning ability is correlated with age, working memory, long-term memory, attention and intelligence to different degrees. Among these cognitive abilities, long-term memory and vigilant attention are two significant predictors of foreign word

learning ability. These results indicate that foreign word learning ability is not a domain-specific ability only related to language learning, but a domain-general ability closely related to cognitive abilities. Moreover, the differences in long-term memory and vigilant attention might be the internal cause of individual differences in foreign word learning ability. 3) (RQ3) In the process of constructing vocabulary knowledge, it is found that P200, N400 and P600 effects are induced in different brain regions, and that these effects might correspond to different mental activities during vocabulary acquisition. Most importantly, the P600 component is an important neural marker of lexical semantic access, and has special meanings in the process of constructing lexical semantic representation. These results have been further demonstrated in a repetitive EEG experiment. 4) (RQ4) The neural predictors of individual vocabulary learning ability have been found both before and during vocabulary learning. In other words, the average amplitude of P600 induced in task state and the alpha band power (including the strength of frontal—occipital functional connectivity) measured in resting state can significantly predict the individual differences of foreign word learning ability.

In general, from the perspective of individual difference, we conduct a progressive and systematic study on foreign word learning ability in accordance with the overall framework of “Description (phenomenon)—Interpretation (mechanism)—Prediction (behavior) — Verification (conclusion)”. Above all, our research is innovative in terms of research perspective, research method and research content, which has made a certain contribution to uncovering the brain mysteries of individual differences in foreign word learning ability.

**Keywords:** Foreign word learning ability; individual difference; neural mechanism; cognitive ability; EEG; reproducibility