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Linguistic and Perceptual Symbol Representation Comparison: Behavioral and Event-Related Potential (ERP) Evidence for Their Effects on Foreign Language Vocabulary Acquisition

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Abstract: This study compared the influence of linguistic symbol and perceptual symbol representations on vocabulary memory encoding and recognition during foreign language vocabulary learning through behavioral and electroencephalography (EEG) experimental techniques, aiming to investigate the mechanism of semantic representation on vocabulary acquisition. The behavioral results indicated that there was no significant difference in the subjective judgments of vocabulary learning effectiveness between participants under linguistic symbol and perceptual symbol representations. However, the latter exhibited a higher accuracy rate in vocabulary recognition compared to the former. The EEG results revealed that, during the vocabulary encoding stage, perceptual symbol representations elicited a more correct late positive component (LPC) compared to linguistic symbol representations. In the vocabulary recognition stage, perceptual symbol representations induced a larger N400 component, and EEG time-frequency analysis demonstrated a more pronounced suppression of μ-band and enhancement of θ-band power under these conditions. The comprehensive findings suggest that, compared to linguistic symbol representations, which facilitate semantic processing but are non-modal, perceptual symbol representations deepen the encoding depth of vocabulary in the late stage and enhance the vivid recognition of vocabulary through perceptual simulation, utilizing multimodal information. This, in turn, promotes semantic retrieval during the recognition stage, ultimately implicitly improving vocabulary learning effectiveness.

1. Introduction

Is there a difference in the impact of language symbols and perceptual symbol representations on foreign language vocabulary acquisition in the process of language learning? What is the cognitive neural mechanism behind this difference?

The theory of linguistic symbols and perceptual symbols has always been controversial in explaining the modal nature of semantic representation. This study compared the effects of language symbols and perceptual symbol representations on vocabulary memory encoding and recognition during foreign language vocabulary learning using behavioral and EEG experimental techniques.

This provides empirical support for integrating the two symbol representations and helps to reveal the mechanism of semantic representation's impact on vocabulary acquisition.

This study has significant implications for the development of foreign language teaching and learning strategies. Assuming that perceptual symbol representation can deepen the depth of late stage encoding of vocabulary compared to language symbol representation, and through perceptual simulation, use multimodal information to improve the visual recognition of vocabulary, thereby promoting semantic retrieval in the recognition stage and ultimately implicitly improving vocabulary learning effectiveness, it means that in daily language (especially foreign language) education and teaching, attention should be paid to strengthening the training of perceptual symbol representation modes, so that learners can flexibly use multimodal experiences such as sensory perception and motor perception to improve the richness of language representation, in order to achieve deep processing of language materials and avoid the mechanical and boring learning process caused by a single abstract language symbol representation.

2. Literature Review

2.1 Semantic Representation and Its Theoretical Development

Semantic representation refers to the cognitive process in which the human brain encodes and extracts meaning from textual information to serve activities such as speech and memory. In the process of acquiring foreign language vocabulary, learners need to first complete the understanding of the meaning of the vocabulary through semantic representation in order to achieve further memory learning. Therefore, semantic representation is a prerequisite for vocabulary comprehension and memory [1] [2]. There are two divergent views in the theoretical evolution of semantic representation. The traditional cognitive view, represented by linguistic symbol representation, holds that linguistic symbols are carriers of semantic representation with non modal properties. Conceptual information is transmitted through linguistic symbols and the propositional network formed between symbols, and information processing is carried out in a computer like logical operation to achieve semantic representation[3]. The embodied cognition view, represented by perceptual symbol representation, holds that the carrier of semantic representation is perceptual symbols with image embodied (or multimodal) features. Rich perceptual and emotional experiences participate in the representation process through perceptual simulation, making them exhibit the perceptual characteristics of images [4]. The theories of linguistic symbols and perceptual symbols each have their own interpretation of the modal nature of semantic representation. With the accumulation of research in psycholinguistics and related cognitive neuroscience, the view of integrating two types of symbolic representations has gained increasing recognition. The viewpoint of symbol integration suggests that there are two meaning processing pathways in the human brain, one originating from the abstract language symbol system and the other from sensory and perceptual neural signals, respectively involving language symbols and perceptual symbol systems. The complete knowledge representation system is jointly shaped by these two symbol systems[5] [6]. The cognitive characteristics of the two symbol representation modes are different and each is suitable for different cognitive activities. Specifically, linguistic symbol representation can achieve rapid semantic access through non modal information transmission, but its cognitive processing is shallow and rough, thus playing a major role in simple and superficial language comprehension activities; The representation of perceptual symbols requires deep perceptual simulation to achieve semantic access through multimodal information processing. Therefore, its processing of materials is deep and refined, but its cognitive efficiency is relatively low, making it dominant in complex and deep language comprehension tasks. The concept of symbol integration has also received some evidence support from cognitive neuroscience. For example, in the field of brain imaging, some studies have found that language processing involves both semantic processing and concept encoding related brain regions such as the lower left frontal lobe and the anterior middle temporal lobe, as well as perceptual feature processing brain regions such as the sensory cortex and motor areas. Brain structures such as the parietal lobule and left insula are also responsible for joint analysis of language and perceptual feature information [7] [8]. The above research provides support for the joint involvement of language and perceptual symbol systems in language processing.

2.2 The role of linguistic symbols and perceptual symbol representation in foreign language learning

The analysis of two representation modes from the perspective of symbol integration provides insights for understanding the semantic representation characteristics in foreign language learning. Firstly, in the process of acquiring foreign language vocabulary, learners need to combine the meaning of words with their pronunciation and form. As a convenient way of semantic access, linguistic symbol representation can help learners quickly understand word meanings for subsequent memorization. Therefore, linguistic symbol representation is a frequently used representation pattern in foreign language learning activities. Previous studies have provided support for this. Firstly, research on second language acquisition indicates that foreign language learners often rely on their mother tongue to achieve semantic access to foreign language vocabulary. Secondly, research on second language cognition has found that proficiency in a foreign language can reverse regulate the role of the mother tongue in semantic communication. The lower the proficiency in a foreign language, the more pronounced the phenomenon of mother tongue dependence in foreign language processing [9]. Thirdly, foreign language proficiency also positively moderates the contribution of perceptual symbol information in semantic comprehension. Bilinguals are more likely to activate the perceptual symbol information involved in the processing of more familiar foreign vocabulary to a greater extent . The above research indicates that for most people, their mother tongue plays a major role in the semantic representation of the foreign language during the low proficiency stage of foreign language learning. When faced with unfamiliar foreign language vocabulary, learners often rely on their mother tongue to obtain propositional meaning information to quickly represent foreign language semantics, while the application of perceptual symbol information such as perceptual movement is relatively limited. Therefore, the process of foreign language learning often reflects the characteristics of language symbol representation.

3. Research hypothesis

(1) The accuracy of foreign language vocabulary recognition under perceptual symbol representation is significantly higher than that under linguistic symbol representation, but there is no significant difference in the subjective judgment results of participants on vocabulary learning effectiveness between the two representation modes. The influence of semantic representation mode on foreign language vocabulary acquisition is more reflected in the implicit recognition process.

(2) Compared to linguistic symbol representation, perceptual symbol representation can promote late stage deep encoding in vocabulary recognition, thereby providing more refined encoding processing.

(3) In the memory retrieval stage of vocabulary, compared with linguistic symbol representation, perceptual symbol representation promotes the activation of multimodal semantic information through enhanced perceptual simulation, and further improves the level of visual processing of vocabulary, thereby promoting semantic retrieval of vocabulary and ultimately enhancing the effectiveness of vocabulary learning.

4. Research Methods

4.1 Experimental purpose

This study examines and compares the effects of linguistic symbols and perceptual symbol representations on the memory encoding and recognition processes of foreign language vocabulary, and tests the independent mechanisms of the two semantic representation modes on foreign language vocabulary acquisition.

4.2 Participants

According to Cohen's (2013) research, the ideal statistical test power and effect size both need to be higher than 0.8. This study used GPower software based on this standard (http://www. gpower. hhu.de/)Estimate that the total sample size required for a single factor two-level intergroup design is 52. Based on this number, 59 non foreign language major college students (including 20 male students) were recruited and randomly assigned to two experimental groups for the experiment. All participants had normal naked or corrected vision, and their native language was Chinese. The average age was 21 ±2.37 years old.

4.3 Experimental Materials

In order to facilitate the manipulation of the semantic representation methods (especially perceptual symbol representation) of the subjects and control the semantic complexity of the experimental materials, this study takes spatial orientation words as an example and selects "up" and "down" semantics as learning objects. At the same time, in order to effectively simulate the learning process and ensure that the number of experimental trials meets the requirements of EEG signal processing, vocabulary was selected from completely unfamiliar languages (such as Russian, Arabic, Thai, Mongolian, etc.) of the subject population. Finally, 80 multilingual vocabulary words involving the meanings of "up" and "down" were selected, all of which did not contain stroke or letter information related to "up", "down", "up", or "down" to prevent participants from engaging in strategic processing during the learning process. Finally, form four word lists, each consisting of 10 semantic foreign words for "up" and "down", for the vocabulary memory encoding stage, and match the length, perceptual features, etc. of the four sets of vocabulary. In addition, this study selected several foreign vocabulary words with other meanings as filling materials for the recognition stage according to the above criteria (10 word lists per group). The same word list was used for both characterization conditions in the experiment.

4.4 Variables

Adopting a single factor inter subject design. The independent variable is the semantic representation pattern of the memory encoding stage, which is divided into two levels: linguistic symbol representation and perceptual symbol representation; The dependent variable is the memory effect of the subjects on foreign vocabulary, and the behavioral indicators include the subjects' JOL scores on vocabulary during the encoding stage and the accuracy during the recognition stage; EEG indicators include LPC components induced during the encoding stage; The N400 component induced by the recognition stage, as well as the time-frequency domain μ and θ waves.

Secondly, in order to separate the two representation methods as much as possible in the process of vocabulary learning, the study adopted an inter subject design, in which participants only received one type of symbolic material repeatedly. Through the repeated programmatic learning of a single symbol initiating stimulus, the vocabulary learning under the two experimental conditions focused on using different representation methods as much as possible, achieving experimental separation.

4.5 Experimental Procedure

The experimental process is divided into a memory encoding stage and a recognition stage for foreign language directional words.

In the coding stage, participants learn vocabulary by sequentially presenting schematic materials and foreign language vocabulary. The subject wears the electrode cap and sits in front of the computer. First, the fixation point "+" is presented in the center of the screen. After a random time of 500-1000ms, a schematic material is presented for 1200ms, indicating the meaning of the foreign vocabulary that needs to be memorized afterwards. The indicative material under the condition of language symbol representation is the Chinese characters "up" or "down" presented in the center of the field of view, which induce the subjects to represent the language symbols of subsequent foreign directional words through Chinese characters; The schematic material under the condition of perceptual symbol representation is to present an arrow animation moving upwards or downwards, indicating the corresponding spatial orientation, and then induce the subject's perceptual symbol representation of the subsequent foreign language directional words through spatial perception. Subsequently, a foreign vocabulary with corresponding meanings was presented at the location of the reference material. To control the learning time of the subjects, the vocabulary was uniformly presented for 5000 ms. The subjects were required to memorize it and record the EEG signals during the memorization of the vocabulary. Finally, the project conducts a learning assessment (JOL) and presents guidance: "Assess how confident you are in recalling the vocabulary you just used in the upcoming test (" 0 "means completely unsure," 10 "means completely confident)". Participants are asked to rate their level of memory mastery of the foreign words just presented on an 11 point scale.

Recognition stage: Participants need to continuously memorize 20 vocabulary words (i.e. one word list) during the memory stage. After the memory is completed, they will perform a 30 second mental calculation and then enter the recognition stage. In the recognition stage, the central fixation point is first presented for 500 ms, followed by a random presentation of a foreign vocabulary (which may be a vocabulary learned during the coding stage, such as an old item or filler material). Participants are required to recognize the vocabulary and classify its semantics, that is, press the "F" key for "up", the "J" key for "down", and the "space" key for "not learned" (i.e. filler material). During the recognition process, the experimenters recorded the EEG signals of the subjects. Before the formal experiment, participants will engage in a set of exercises to familiarize themselves with the experimental process (the exercise materials are different from the formal experimental materials). The formal experiment is divided into four blocks, with each block completing a set of vocabulary memorization (10 foreign words for "up" and "down") and recognition (10 words for "up", "down", and filling materials). In order to prevent fatigue among the subjects, they will be given sufficient rest between the blocks.

4.6 Experimental Instruments

The instruments used in this study are mainly electroencephalography (EEG) recording devices, combined with behavioral experimental techniques.

4.7 Data Analysis

EEG component analysis:

Researchers analyzed EEG components during the vocabulary encoding and recognition stages. In the encoding stage, researchers compared the late positive component (LPC) induced under linguistic symbol representation and perceptual symbol representation conditions. In the recognition stage, researchers analyze N400 components related to semantic processing.

EEG time-frequency domain analysis:

By examining the characteristics of μ waves (8-13 Hz) and θ waves, we aim to further reveal the neural mechanisms underlying the process of vocabulary recognition under these two characterization conditions.

5. Educational significance

By comprehensively comparing the two sub components of semantic representation, namely language symbols and perceptual symbol representation, the impact of perceptual symbol representation on foreign language vocabulary memory encoding and semantic recognition was revealed, revealing the positive role of perceptual symbol representation in foreign language vocabulary learning. Therefore, daily language (especially foreign language) education and teaching should focus on strengthening the training of perceptual symbol representation modes, so that learners can flexibly apply multimodal experiences such as sensory perception and motor perception to improve the richness of language representation, achieve deep processing of language materials, and avoid the mechanical and boring learning process caused by a single abstract language symbol representation.

6. Potential challenges and limitations

The advantage of fast semantic access in language symbol representation may balance the gap in JOL scores. This can be supported by real-life learning situations, where foreign language learners tend to rely on native language information to learn foreign vocabulary. This can to some extent reduce the cognitive burden of vocabulary learning, provide participants with a convenient and smooth learning experience, and improve learning judgment. Therefore, after proving that perceptual symbol representation provides cognitive advantages for foreign language learning, further consideration should be given to how learners can consciously and actively utilize this advantage in the actual learning process.

In addition, the application of the two representation modes needs to consider practical situations: according to the theory of symbol integration and relevant empirical research, on the one hand, language symbols are easier for learners to quickly obtain semantic information of learning materials compared to perceptual symbols, and actual foreign language learning cannot be completely separated from language symbol information (for example, it is difficult to get rid of the role of the mother tongue when learning a foreign language); On the other hand, although perceptual symbol representation has the advantage of fine processing, it also has the disadvantage of low processing efficiency, and it has certain requirements for the teaching environment, learners' foreign language proficiency, and cognitive investment. Therefore, it is not realistic for language learning to rely entirely on perceptual symbol representation.

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