

# Developmental Changes in the Role of Semantic Radicals in Lexical Processing in Third Graders, Sixth Graders, and College Students

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The role of the semantic radical is important to understand the cognitive mechanisms of lexical processing. However, it is still unclear about the cognitive accounts of developmental changes of the semantic radical on lexical processing, including the sublexical and the neighborhood size account. In the present study, we address this issue by recruiting 60 third graders, 54 sixth graders and 28 college students. Participants were tested using the lexical decision task. They had to decide whether a visual symbol was a real Chinese character. Frequency (high, low) and radical combinability (high, low) were independently varied to study lexical processing. There were two main results. First, a significant frequency effect was found across three age groups during the lexical decision task, suggesting that lexical access was involved in the task for participants. Second, for the third graders there was a significant effect on radical combinability effect, with better sensitivity performance on characters with high combinability. This finding suggests that third graders may rely more on the knowledge of the sub-lexical component (i.e., semantic radical) within a character to facilitate their lexical decision judgments. This result can be explained by the bi-directional activation model, using the interactive activation of sublexical and lexical information during lexical processing. In contrast, there was no significant effect on radical combinability in both the sixth graders and college students. We will present several views and future directions to explain the differences in radical processing between children and adults.

**Keywords:** *lexical decision, development, semantic radical, frequency*

## Summary

In the Chinese writing system, approximately 80% of the characters are phonetic compounds (phonograms) that consist of a semantic radical and a phonetic radical (Y. G. Zhou, 1978). Semantic radicals may indicate the semantic category of the character and phonetic radicals may provide the cue for the character's pronunciation. Semantic radicals carry clues about the semantic category of a character. A given semantic radical may combine with different phonetic radicals to form a variety of characters. For example, the semantic radical “氵” (water) appears in

a variety of characters, such as “江” (river), “海” (ocean), and “湖” (lake), indicating that these characters are related to the category of water.

Studies have found that semantic radicals play a role in lexical processing. In these studies, adults performed semantic judgments faster when the target character shared the same semantic radical as the prime character. Likewise, adults performed faster when the meaning of a semantic radical was consistent with the meaning of a character. Moreover, in the literature on literacy development, researchers have also found that knowledge of semantic radicals is important for children

when learning Chinese characters. Studies have shown that children do not develop an awareness of semantic radicals until the third grade (Anderson et al., 2013; Ho, Ng, & Ng, 2003). Third graders could improve their performance in character recognition by using knowledge of semantic radicals, which first and second graders could not. These studies used a bottom-up view to explain this developmental change, suggesting that children learn the functions of semantic radicals first, and then apply them to Chinese characters that contain them (Ho, Ng, et al., 2003; McBride-Chang, Shu, Zhou, Wat, & Wagner, 2003; Shu & Anderson, 1997). Thus, studying the role of semantic radicals is important for understanding the cognitive mechanisms of lexical processing.

As semantic radicals may appear in various characters, we can use their combinability to explore their role in lexical processing. The combinability of semantic radicals has been defined as the total number of characters that may be shared by a given semantic radical. The effect of radical combinability has been a controversial issue (Hsiao, Shillock, & Lavidor, 2007). Taft and Zhu (1997) manipulated radical combinability (high, low), and showed that high radical combinability facilitated performance only when the radicals were on the right side of a character. Feldman and Siok (1997) argued that Taft and Zhu's results were confounded by the positions and functions of the radicals. Thus, Feldman and Siok further distinguished the positions and functions of radicals by manipulating semantic radicals' positions and combinability. In contrast to Taft and Zhu, Feldman and Siok found that semantic radical combinability only had a facilitatory effect when the semantic radical was on the left side of a Chinese character.

M. J. Chen and Weekes (2004) used the same manipulation as Feldman and Siok (1997) and had two additional variables for semantic radicals (consistency and transparency) in a lexical decision task. They found that semantic radical combinability had no significant effect on the lexical decision task. However, using a semantic categorization task, M. J. Chen and Weekes found an interaction among combinability, consistency, and transparency. Their results showed that high semantic radical combinability facilitated performance

in a transparent and low-consistency condition during semantic judgments. In contrast, high semantic radical combinability inhibited performance in a transparent and high-consistency condition. These findings suggest that multiple factors should be considered when exploring the roles of semantic radicals, including their function and position, and the nature of the task.

To conclude, the aforementioned studies provided some evidence that semantic radicals indeed play a role in lexical processing in adults. However, the cognitive accounts of developmental changes in semantic radicals on lexical processing are still unclear. To our knowledge, this was the first developmental study to manipulate semantic radical combinability to explore age-related changes in the role of semantic radicals on lexical processing. Moreover, studies have found that the role of semantic radicals might be moderated by frequency (H. C. Chen, 1984; Shu & Anderson, 1997). Thus, both frequency and semantic radical combinability are taken into account in the present study to explore developmental changes in the role of semantic radicals during lexical processing.

## Aims

The present study had two aims. First, to investigate developmental changes in the role of semantic radicals in lexical processing, the study compared the combinability of semantic radicals in lexical decision-making in third graders, sixth graders, and adults. Second, to understand the role of semantic radicals during lexical processing, the study adopted a lexical decision task and manipulated the frequency (high, low) and radical combinability (high, low) as independent variables in the task.

Previous child studies have suggested a shift from bottom-up processing to top-down processing to recognize Chinese characters upon reaching late years of elementary school (Frith, 1985; Gough, Juel, & Griffith, 1992; Ho, Yau, & Au, 2003; K.-C. Hung, Lee, Chen, & Chou, 2010; Lee, Hung, & Chou, 2014). Therefore, we propose the following three hypotheses. First, third graders will acquire a large set of Chinese characters and begin to develop an awareness of the sub-lexical components of a

character (Ho, Yau, et al., 2003). If semantic radicals play a sub-lexical role in lexical decision-making, they will have a facilitatory effect on radical combinability for third graders. Second, as more proficient readers, sixth graders may develop more mature top-down processing than third graders in lexical decision-making (Frith, 1985; Gough et al., 1992; Ho, Yau, et al., 2003; K.-C. Hung et al., 2010; Lee et al., 2014). Reliance on sub-lexical information may decrease in sixth graders during lexical decision-making. This decreased reliance on sub-lexical information from the third to sixth grades is supported by previous child studies (H. F. Chen, 1999; H. S. Huang, 1999; C.-C. Wang, 2005; Qin & Wang, 1999). Third, for college students, if semantic radicals play a sub-lexical role in lexical decision-making, they will have a facilitatory effect on radical combinability during lexical decision-making. In contrast, if college students use a group of characters with the same semantic radical (i.e., neighbors) in lexical decision-making, an inhibitory effect on radical combinability may be found (H. C. Chen, 1984; Yang & Wu, 2014).

## Methods

The present study consisted of four experiments using a lexical decision task to investigate the developmental role of semantic radicals on lexical processing. Experiment 1 tested 60 third graders, Experiment 2 tested 54 sixth graders, Experiment 3 tested 28 undergraduate students, and Experiment 4 tested 10 undergraduate or graduate students. In Experiments 1 and 2, the participants were visually presented with 100 Chinese characters and 100 pseudo-characters printed on paper one at a time. They were asked to decide whether these visual symbols were real Chinese characters or not. The 100 characters were equally divided into four types by two factors: frequency (high, low) and radical combinability (high, low). The number of strokes, visual complexity, and position of the semantic radical were controlled across the four conditions. Pseudo-characters were created by replacing the radicals of characters with other radicals to form visual symbols complying with character-forming rules but not listed in

the dictionary. Experiment 3 was a computerized version of the paper-and-pencil task conducted in Experiments 1 and 2. To guarantee that the results of the computerized version were compatible with those of the paper-and-pencil version, we ran Experiment 4 in the same format as Experiments 1 and 2. The two sets of results for Experiments 3 and 4 were compatible. Thus, in the following analysis, we directly compare the data collected in Experiments 1, 2, and 3.

## Results

The experiments had three independent variables: age group (third graders, sixth graders, and adults), frequency of characters (high, low), and semantic radical combinability of characters (high, low). To accurately evaluate the participants' lexical decision-making performance and avoid response bias, we used signal detection theory (Tanner & Swets, 1954) to calculate the sensitivity index  $d'$  as the dependent variable. In the following analysis, a 3 (age)  $\times$  2 (frequency)  $\times$  2 (semantic radical combinability) analysis of variance (ANOVA) was performed on  $d'$ . We found three major results. First, there was a significant interaction between age frequency. A simple main effect analysis was further conducted. The differences in the three age groups were examined in high and low frequency conditions. Higher  $d'$  was found in the sixth graders and adults than the third graders in the low frequency, but not the high frequency, condition. Second, a significant frequency effect was found across the three age groups in the lexical decision task. Third, a significant interaction was found between semantic radical combinability and age. A simple main effect analysis was further conducted. The third graders obtained higher  $d'$  in the high radical combinability than the low radical combinability condition. The effect of radical combinability was not significant for the sixth graders or college students.

## Discussion

### Developmental Changes in Frequency Effect

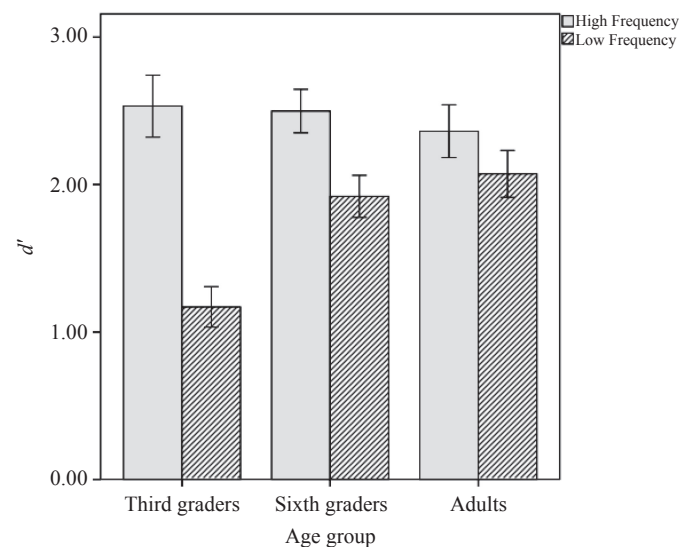
There was a significant interaction between age and

frequency. Further analysis revealed a developmental change in the frequency effect, as shown in Figure 1. The difference in  $d'$  between the high and low frequency conditions decreased as age increased. This developmental change could also be explained by different developmental patterns between these two frequency conditions. In the high frequency condition, there was no significant difference among the three age groups, indicating that all of the participants had comparable ability to distinguish high frequency characters from pseudo-characters. However, in the low frequency condition, there was a significant difference among the three age groups; sixth graders and adults performed better than third graders in distinguishing low frequency characters from pseudo-characters, and there was no significant difference between sixth graders and adults. These findings suggest that sixth graders have a greater ability to distinguish low frequency characters from pseudo-characters than third graders, perhaps due to an age-related increase in vocabulary size.

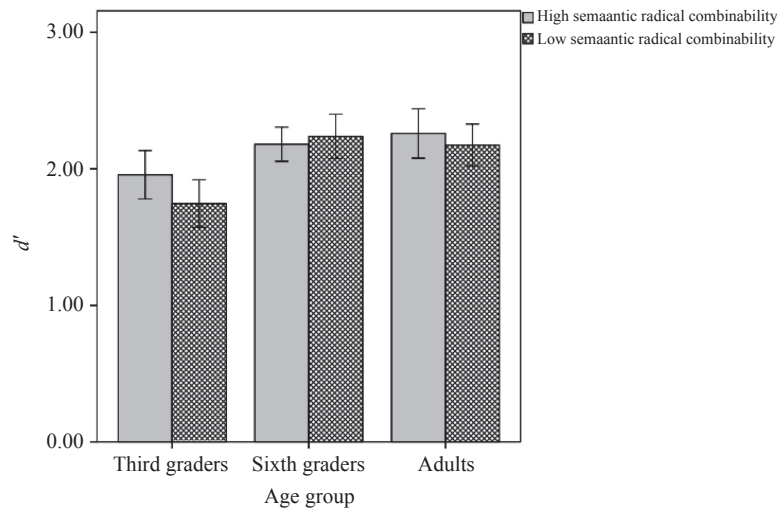
### Developmental Changes in the Effect of Semantic Radical Combinability

There was a significant interaction between age and semantic radical combinability. Further analysis revealed that the radical combinability effect was found only in

third graders, not in sixth graders and adults, as shown in Figure 2. The third graders performed with better sensitivity in the high radical combinability condition than the low radical combinability condition. This finding is in line with P. D. Liu, Chung, McBride-Chang, and Tong's (2010) finding that fourth graders use semantic radical information to facilitate lexical processing. However, P. D. Liu et al. did not manipulate frequency or semantic radical combinability. In the present study, we manipulated the frequency and combinability of semantic radicals. Our results revealed that semantic radical combinability had a facilitatory effect across the high and low frequency conditions in third graders. This finding supports the assertion that third graders use knowledge of semantic radicals to facilitate character recognition during lexical processing. In contrast, for both sixth graders and adults, radical combinability had no significant effect. Our finding for adults is consistent with M. J. Chen and Weekes's (2004) findings, although they did not manipulate the frequency factor. When frequency was considered in Ding, Peng, and Taft's (2004) study, a facilitatory effect on radical combinability was found only in the low frequency condition. Ding et al. suggested that the processing of high frequency characters was highly automatized, such that there was no room to further improve performance. In the present study, we selected characters based on the corpus of elementary students. In



**Figure 1.** Interaction between age group and frequency in terms of  $d'$ .



**Figure 2. Interaction between age group and semantic radical combinability in terms of  $d'$ .**

other words, these characters would be easier and quicker to process for adults and sixth graders than third graders, indicating that a significantly facilitatory effect on semantic radicals during lexical processing is less likely.

## General Discussion

In the present study, we used a lexical decision task to investigate developmental changes in the role of semantic radicals on lexical processing. There was a significant frequency effect across three age groups, with higher  $d'$  in the high frequency condition than the low frequency condition. This finding suggests the involvement of lexical access in these three groups, as the frequency effect is one the most important indicators for eligible experimental tasks that examine the nature of lexical access (I.-M. Liu, Wu, & Chou, 1996; Wu, Yang, & Lin, 2013). Accordingly, the lexical decision task was able to explore the role of semantic radicals in lexical processing.

In the present study, if semantic radicals play a sub-lexical role in lexical processing, a facilitatory effect of radical combinability is obtained. Our results found a facilitatory effect of radical combinability only in third graders. This finding suggests that third graders may rely more on knowledge of the sub-lexical component (i.e., semantic radical) of a character to facilitate lexical

decision judgments. This result can be explained by the bi-directional activation model, using the interactive activation of sub-lexical and lexical information during lexical processing (Lee, Hung, & Chou, 2014; X. Zhou & Marslen-Wilson, 1999). In contrast, radical combinability had no significant effect in either the sixth graders or college students. These findings are not in line with Y.-H. Hung, Hung, Tzeng, and Wu's (2014) findings. Y.-H. Hung et al. found an effect of semantic radicals and thus made a claim about their sub-lexical role in adults' lexical processing. However, the most influential factor—frequency—was not manipulated in their experiment. As previously mentioned, in the field of psycholinguistic studies, a frequency effect should be used to infer the involvement of lexical access (Wu et al., 2013). Thus, Y.-H. Hung et al.'s results might not be able to support the involvement of lexical access in adults.

A confounder of Y.-H. Hung et al.'s (2014) study is the lack of manipulation of neighborhood size. The neighborhood size of a character is defined as the number of orthographically similar characters with the same radical. The neighborhood size effect indicates the integration of contextual knowledge across orthographically similar characters instead of sub-lexical processing within a character. By varying neighborhood size, recent studies have shown a reliable inhibitory effect on lexical access (Wu & Chen, 2003; Yang &

Wu, 2014). However, in the present study, manipulating neighborhood size did not show an inhibitory effect in adults. The differences between the present study and previous studies could be explained by the difference in the neighborhood size number. Neighborhood sizes that show an inhibitory effect are mostly under 10 (Wu & Chen, 2003; Yang & Wu, 2014), and the neighborhood sizes used in the present study are mostly over 10, with some even over 100. The different effects of neighborhood size on lexical processing are related to a logarithm curve (i.e., Fechner's function). We take the phonetic radical as an example. The phonetic neighborhood sizes that show an inhibitory effect are under 10 and thus fall at the shape slope on the left side of the logarithm curve (Wu & Chen, 2003; Yang & Wu, 2014). In the present study, the semantic neighborhood sizes are more than 10 and thus fall near the flat slope on the right side of the logarithm curve. Given that larger neighborhood sizes produce smaller changes by Fechner's function, it was difficult to obtain a significant effect of semantic neighborhood size on lexical processing in the present study.

Furthermore, in the present study, the lack of a facilitatory effect on semantic radicals is not in line with the findings reported by Ding et al. (2004) and Fang and

Wu (1989). A possible explanation for this discrepancy is task demand. Short pre-exposure to a prime (Ding et al., 2004) and illusory conjunction (Fang & Wu, 1989) are more sensitive to early attention or perception processing than lexical access. In contrast, lexical decision-making is more sensitive to important lexical features, such as frequency effect and semantic integration. Thus, it is important to compare different tasks to further understand the underlying mechanisms of visual character/word recognition.

## Conclusions

In conclusion, third graders demonstrated better performance for the high than low radical combinability condition, which indicates that semantic radicals play a role in lexical processing. Thus, a bi-directional activation model was used to explain the radical effect in third graders. In contrast, sixth graders and college students, more proficient readers, may rely less on semantic radicals during lexical processing. Developmental changes may suggest a shift from radical components to whole characters, with further consideration of neighborhood size and task demand.