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The Effect of Arousal on Chinese Word Segmentation

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Abstract

In the absence of inter-word spaces, Chinese readers rely on other available information for word segmentation. A previous study demonstrated that the valence of words influences word segmentation (Huang et al., 2024). The current study further investigated the influence of arousal, another key dimension of emotion, on Chinese word segmentation. We first reanalyzed the segmentation results from Huang et al.'s study and found that arousal had an independent effect on Chinese word segmentation. In the experimental study, we manipulated the arousal levels of words while keeping valence at a neutral level. The results provide evidence that the arousal of words can affect Chinese word segmentation, with higher-arousal words being more likely to be segmented than low-arousal words. Moreover, our findings are also essential for understanding the impact of arousal on word processing and suggest that it impacts the early stage of activating a word's representation.

Keywords: arousal, word segmentation, lexical competition, valence

The Effect of Arousal on Chinese Word Segmentation

Chinese differs from alphabetic languages (such as English) in several aspects, including the absence of inter-word spaces to mark word boundaries explicitly. To achieve successful comprehension, Chinese readers must utilize other available information for word segmentation. A crucial question is identifying the types of information on which Chinese readers depend for word segmentation. Previous studies have primarily examined how linguistic factors, such as word frequency and sentence context (Chen et al., 2024; Huang et al., 2021; Huang & Li, 2024; Ma et al., 2014), influence word segmentation. Recently, Huang et al. (2024) found that high-level information, such as the valence of words (positive or negative), was also used by Chinese readers for segmentation, with emotional words being more likely to be segmented as words when other factors are controlled. However, emotion is typically defined along two dimensions: valence and arousal (Kuperman et al., 2014; Russell, 2003). The impact of arousal on Chinese word segmentation remains unclear, which is the focus of the present study.

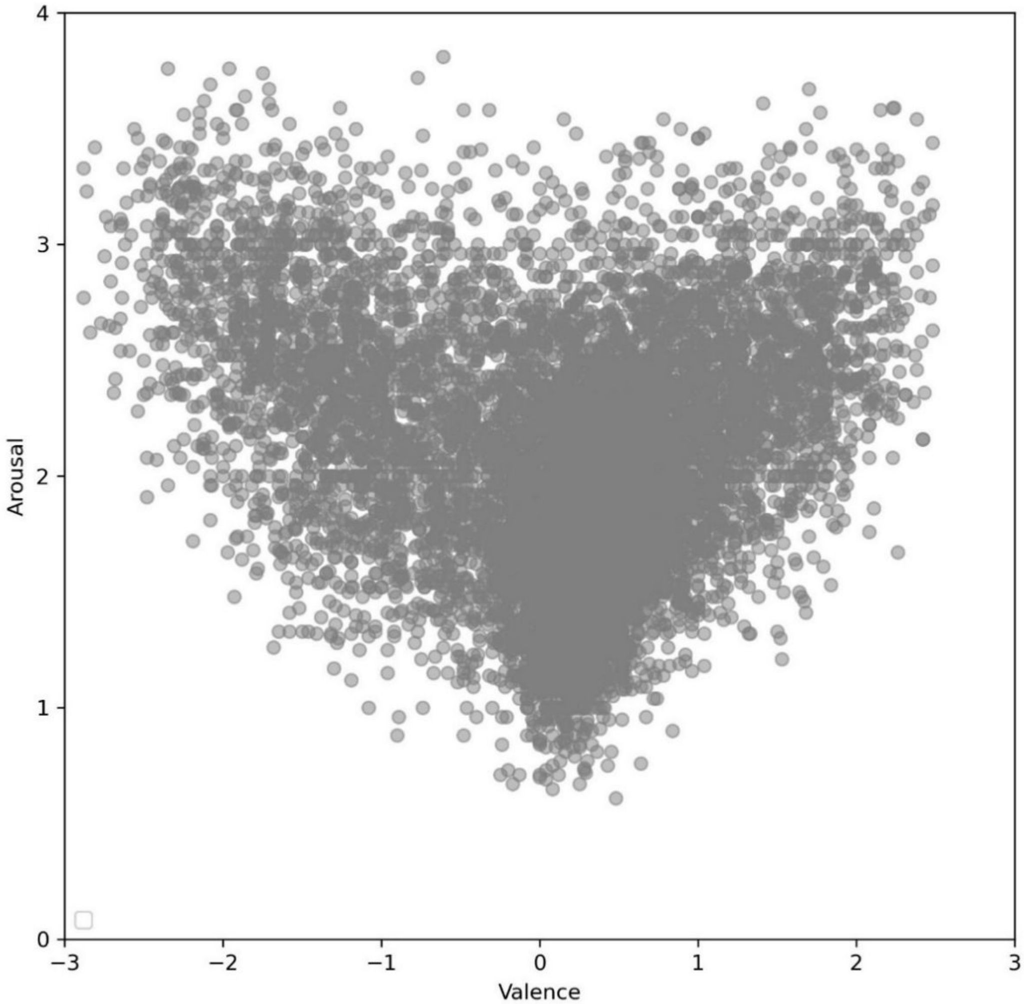
The absence of inter-word spaces can lead to ambiguities in word boundaries, with an *Overlapping Ambiguous String* (OAS; Gan et al., 1996; Sun & Zou, 2001) being one example. An OAS (e.g., "先天使") typically consists of three characters (ABC, representing the characters from left to right), where the middle character can form distinct words with both the preceding character (word AB; e.g., "先天", meaning *innate*) and the following character (word BC; e.g., "天使", meaning *angel*). During sentence reading, Chinese readers must determine which word the middle character B belongs to (Hsu & Huang, 2000). Previous studies have shown that word frequency and word position affect segmentation (Huang et al., 2021; Ma et al., 2014). Specifically, the middle character is more likely to be assigned to the high-frequency word. Furthermore, as Chinese is read from left to right, the left-positioned word receives attention earlier than the right. Therefore, when other factors are controlled, word AB is more likely to be segmented than word BC (Huang & Li, 2020; Huang et al., 2021; Li et al., 2009; Ma et al., 2014, Experiment 3). For example, Huang et al. (2021) showed participants OASs in isolation, and asked them to indicate where the word boundaries were. The results showed that an OAS with equally matched frequencies between word AB and BC is segmented as AB-C about 60% of the time.

Based on these findings, a computational model known as the *Chinese Reading Model* (CRM; Li & Pollatsek, 2020) was developed to simulate how Chinese readers segment words during reading. According to CRM, all characters within the perceptual span are activated and processed in parallel, and all potential words constituted by these characters are also activated. These activated words inhibit each other and compete for a single winner if they spatially overlap. A word is simultaneously identified and segmented once its activation surpasses a threshold, and each character is assigned to only one segmented word. Taking an OAS as an example, readers need to determine whether the character B belongs to word AB or word BC. This process is more complicated than word identification in spaced languages such as English. For spaced languages, readers rely on inter-word spaces, and then identify the segmented strings. Only those words that match the length of the segmented string are activated, and they compete for a winner. Therefore, word processing in Chinese is not simply equivalent to word identification in English. The CRM successfully simulates the effects of word frequency and the left-side word advantage on word segmentation.

In addition to the factors mentioned above, a recent study demonstrated that the emotional information of words also affects the outcome of Chinese word segmentation (Huang et al., 2024). In that study, participants saw isolated OASs and were asked to indicate the word they recognized first. These OASs were formed by combining a neutral word with an emotional word (either positive or negative) that shared character B. The valence of the emotional words (positive vs. negative) and their position in the OAS (left-side vs. right-side) were orthogonally manipulated. The results showed that both positive and negative words were more likely to be segmented than neutral words when other factors were equal, suggesting that emotional information influences word segmentation outcomes. The observed effect of valence on word processing is generally aligned with previous studies using lexical decision (Wentura et al., 2000), naming (Algom et al., 2004) and natural reading tasks (Hu et al., 2024; Scott et al., 2012; Yan & Sommer, 2015, 2019).

Figure 1

The Distribution of Two-Character Chinese Words' Emotion Information



Note. The distribution of valence and arousal of 9,774 two-character Chinese words, as reported by Xu et al. (2022), with the x-axis and y-axis representing valence and arousal, respectively. Valence was measured by a 7-point scale: -3 (*most negative*) to 0 (*neutral*) to 3 (*most positive*); arousal was measured by a 5-point scale: 0 (*calmness*) to 4 (*excitedness*).

It is important to note that words vary in their valence and arousal. Valence is the extent to which a word is negative or positive; arousal is the extent to which a word is calming or exciting (Bradley et al., 2001). As shown in Figure 1, there are positive (e.g., *intimacy*), negative (e.g., *betray*), and neutral words (e.g., *secret*) among high-arousal words and there are also positive (e.g., *peace*), negative (e.g., *numb*), and neutral words (e.g., *fossil*) among low-arousal words (Russell, 1980). Previous studies have shown that both valence and arousal influence the speed of word identification (Hofmann, 2009; Hu et al., 2024; Kuperman et al., 2014; Recio et al., 2014; Robinson et al., 2004; Yan & Sommer, 2015, 2019). For example, a corpus study (Kuperman et al., 2014) analyzed the reaction times (RTs) of lexical decision and naming tasks based on 12,658 English words. The results showed that negative words were recognized slower than positive words, and high arousal words were also recognized slower than low arousal words, with no interaction between valence and arousal. An eye-tracking reading study (Scott et al., 2012) also found that the single fixation duration (SFD) of neutral words was longer than that of negative and positive words in low-frequency word. For high-frequency words, the SFD of neutral and negative words was longer than that of positive words. Similar findings have also been observed in Chinese reading. For example, Xu et al. (2022) found that both valence and arousal can negatively predict RTs and error rates of the lexical decision task based on 11,310 Chinese words. Yan and Sommer (2015) inserted emotional and neutral words in sentence, and they found that fixation durations on foveal neutral words were longer than positive and negative words. Although these studies used different tasks and the results are not always consistent, they collectively show that both valence and arousal affect word processing.

These results raise a question regarding whether arousal can also affect Chinese word segmentation. Notably, in the study by Huang et al., the arousal of emotional words was higher than those of neutral words (see Figure 2). For instance, for the OAS “先天使”, word AB “先天”

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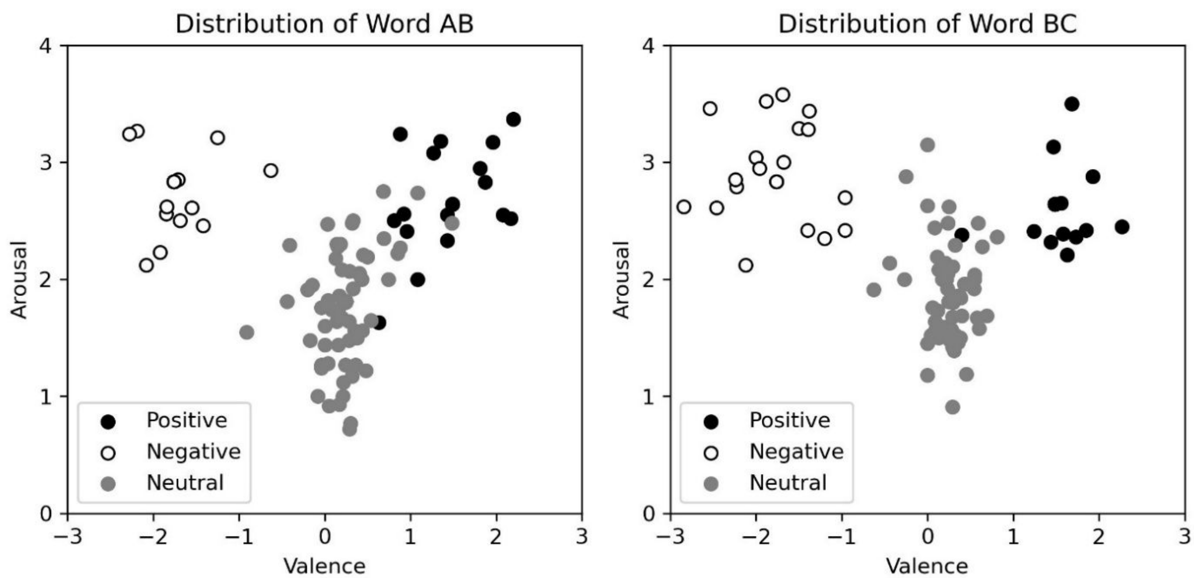
eaning *innate*) was a neutral word with low absolute valence and low arousal, and word BC “天使” (meaning *angel*) was a positive word with high valence and high arousal. Therefore, it is unknown whether the effects observed by Huang et al. were caused by the valence difference or the arousal difference between constituent words of the OASs. In addition, previous studies (Hu et al., 2024; Yan & Sommer, 2015, 2019; Xu et al., 2022) regarding the effects of emotional information on Chinese word identification used stimuli with clear and unambiguous word boundaries. Thus, the effect of arousal on Chinese word segmentation needs further investigation.

Figure 2

The Distribution of Valence and Arousal of Stimuli in Huang et al. (2024)



Note. The distribution of valence and arousal of stimuli in Huang et al. (2024), with the x-axis and y-axis representing valence and arousal, respectively. Valence was measured by a 7-point scale: -3 (*most negative*) to 0 (*neutral*) to 3 (*most positive*); arousal was measured by a 5-point scale: 0 (*calmness*) to 4 (*excitedness*). Both valence and arousal were derived from Xu et al. (2022).

To understand the effects of arousal on word segmentation, we investigated whether the arousal of words affects Chinese word segmentation. According to the CRM, potential word candidates composed by characters within the perceptual span compete with each other for a single winner; and once a word wins the competition, it is identified and segmented simultaneously. One possibility is that arousal can affect word segmentation. In line with this hypothesis, the Interactive Activation Model (IAM) for alphabetic languages assumes that the representations formed at different levels are linked through feedforward and feedback connections, and thus high-level information can provide feedback to the word level (Carreiras et al, 2014; McClelland, 2016; McClelland & Rumelhart, 1981; Stolz & Besner, 1996). As one kind of high-level information, arousal of words may be partially activated along with the activation of word units, which in turn affects the activation of word units and hence the word competition. Another possibility is that arousal only exerts an effect after words are segmented. In line with this hypothesis, the two-stage segmentation strategy (Ma et al., 2014) indicates that the first stage of word segmentation only involves low-level word information such as word frequency, and the high-level information helps to check the initial word segmentation in the later integration stage. Arousal of words may be activated only when words are identified and hence has no chance to influence word segmentation.

To distinguish between the above two hypotheses, we conducted two studies. In the first study, we reanalyzed the segmentation outcome (i.e., the probability of AB-C segmentation) of Huang et al. (2024), which involved emotional words and neutral words. Based on the data in Huang et al.'s study, we can detect the effect of arousal for emotional words. In the second study, we conducted an experiment in which participants read OASs composed by neutral words that varied only in arousal level to isolate the effect of arousal on word segmentation for neutral words. In the study, participants were asked to decide whether word AB or word BC was the word they initially identified. We separated the effect of arousal from valence in the second study to avoid the interaction between arousal and valence that may complicate interpretation (The effect of arousal in emotional words had already tested in the first study). Moreover, neutral words provide greater variance in arousal than positive and negative words.

Different hypotheses make different predictions about the outcome of word segmentation. If the arousal of words influences word segmentation, we should detect its effect both in the reanalysis of previous data involving emotional words and in the experimental study using neutral words. Specifically, word segmentation outcome should vary with arousal level. By contrast, if arousal exerts an effect only after word segmentation, there should be no effect of arousal on word segmentation, regardless of whether emotional words or neutral words are involved. In this case, word segmentation outcomes should be comparable across different levels of arousal.

Analyses of Previous Data

Method

Data Set. We employed the data from Huang et al. (2024), which collected data from 413 participants. In this experiment, participants were asked to complete an OAS segmentation task, in which participants were given a questionnaire and instructed to report the word they first identified. All participants were native Chinese speakers with normal or corrected-to-normal vision and without history of mental or language disorder. The experiment was performed online through the *Wenjuanxing* platform (https://www.wjx.cn/).

Stimuli. The experiment manipulated the valence of words AB and BC of OASs. There were 88 emotional OAS where words AB or BC were negative or positive words and 88 control OASs where words AB and BC were both neutral words. We derived the valence and arousal scores from the database of Xu et al. (2022). We used Xu et al.'s (2022) database rather than Wang et al.'s (2008) and Yao et al.'s (2017) databases which were used by Huang et al., because Xu et al.'s database includes valence and arousal value of 9,774 two-character words, covering all words in both the emotional and control groups adopted by Huang et al. In contrast, the databases by Wang et al. and Yao et al. only cover the emotional group. In addition, Xu et al.'s database can meet our requirement for finding enough stimuli for our experimental study. The valence of negative words was smaller than neutral words (t = -45.78, p < 0.001) and positive words (t = -56.53, p < 0.001), and the valence of neutral words was smaller than positive words (t = -28.23, p < 0.001). For arousal, there was no significant difference for words shared the same valence label (i.e., positive vs. positive, negative vs. negative; ts < 1.33, ps > 0.10). The arousal of negative words was higher than neutral words (t = 19.56, p < 0.001) and positive words (t = 2.81, p = 0.005), and the arousal of positive words was higher than neutral words (t = 15.88, p < 0.001). The frequency and strokes of words were controlled between different groups (Fs < 1, ps > 0.05). The properties of stimuli are shown in **Table *1***.

Table 1

The Properties of Stimuli in Huang et al. (2024)

Properties	**Word AB**			**Word BC**		
	Negative	**Neutral**	**Positive**	**Negative**	**Neutral**	**Positive**
Frequency	0.77 (0.08)	0.78 (0.03)	0.74 (0.08)	0.82 (0.06)	0.78 (0.03)	0.80 (0.06)
Strokes	14.95 (0.89)	14.92 (0.28)	15.95 (0.97)	14.82 (0.48)	14.98 (0.32)	16.23 (0.80)
Valence	-1.73 (0.07)	0.25 (0.02)	1.44 (0.09)	-1.79 (0.10)	0.25 (0.01)	1.53 (0.07)
Arousal	2.77 (0.06)	1.79 (0.03)	2.67 (0.09)	2.90 (0.09)	1.83 (0.02)	2.61 (0.06)

Note. Standard errors are given in parentheses. The unit of log-transformed frequency is the number of occurrences per million (Lexicon of Common Words in Contemporary Chinese Research Team, 2008). The scores of valence and arousal were based on a database (Xu et al., 2022), and a group-level average (based on the Valence Label) will be used if the word cannot be found in the database.

Data Analysis. To explore whether arousal affects word segmentation, we built a *generalized linear mixed-effects model* (GLMM) on segmentation outcome (i.e., the probability of

AB-C segmentation) using data from the study of Huang et al. (2024). Participants' segmentation outcomes (coding response AB-C as 1 and A-BC as 0) were analyzed using GLMM with the *R* 4.4 version of the *lme4* package (Bates et al., 2015; R Core Team, 2022). Valence and arousal of words AB and BC were entered as independent variables in the model. To avoid making the GLMM too complicated, the frequency and strokes which were controlled in words AB and BC were not entered as independent variables. In GLMM 1, only valence of words AB and BC were used as independent variables; in GLMM 2, only arousal of words AB and BC were used as independent variables; in GLMM 3, both the valence and arousal of words AB and BC were entered as independent variables in a single model. Following Barr et al.'s (2013) suggestion, we constructed a model with the maximal random structure that could converge. We first constructed a model with a maximum random factor structure that specified participants and items as crossed random effects, including intercepts and slopes. When the maximal model failed to converge, we used a zero-correlation parameter model and dropped the random components that generated the minimum variances. We reported regression coefficients (*b*s), *SE*s, *z* values (for the segmentation outcomes), and *p*-values of the optimal model.

Results and Discussion

Words were classified as negative (valence < -1), neutral (-1 ⩽ valence ⩽ 1), or positive (valence > 1) according to Xu et al. (2022). It should be noted that the valence scores of Huang et al. (2024) were derived from Yao et al. (2017) and Wang et al. (2008), and the valence scores of some words are different from Xu et al. As a result, eleven items were excluded from the analysis because they were categorized into different valence labels in different databases[1]. For example,

[1] The OASs including one of the following words were excluded: 星空, 钞票, 生日, 喜剧, 迎接, 流星, 拒绝, 误会, 审讯, 权威, 精细. The results of GLMM based on all items can be found in Table A1.

"流星" was classified as a positive word in Huang et al. However, the valence of "流星"(which means *meteor*) is 0.4 in Xu et al. (2022), which should be categorized as a neutral word.

The fixed effects from the GLMMs are shown in **Table 2** (the final GLMMs see **Error! Reference source not found.**). In GLMM 1, the results of valence were consistent with those in Huang et al. (2024): the effect of valence on word segmentation was significant (word AB Positive vs Neutral: $z = 2.58$, $p = 0.010$; word BC Positive vs Neutral: $z = -2.82$, $p = 0.005$; word BC Negative vs Neutral: $z = -2.94$, $p = 0.003$). In GLMM 2, the effect of arousal on word segmentation was also significant (word AB arousal: $z = 0.60$, $p < 0.001$; word BC arousal: $z = -0.80$, $p < 0.001$). In GLMM 3, the effect of arousal on word segmentation remained significant when both the valence and arousal of words AB and BC were entered as independent variables (word AB arousal: $z = 2.07$, $p = 0.039$; word BC arousal: $z = -2.14$, $p = 0.033$). Specifically, the higher the arousal of word, the more likely it is to be segmented. However, in this case, the valence effect of words AB (positive: $z = 0.80$, $p = 0.426$; negative: $z = -0.61$, $p = 0.541$) and word BC (positive: $z = -0.44$, $p = 0.660$; negative: $z = -0.18$, $p = 0.855$) on segmentation was not significant.

These results suggest that arousal exerted an effect in word segmentation. We did not find a significant effect of valence on word segmentation when arousal was also considered in the reanalysis of Huang et al.'s data. This null effect shows some evidence that valence of words does not affect Chinese word segmentation. However, because this is a null effect, it should be read with caution. Future studies should orthogonally manipulate the arousal and valence to clarify their relationship.

Table 2

Results of the GLMM for the Probability of AB-C Segmentation in Analyses of Previous Data

Model	Fixed effects	Estimate	SE	*z*	*p*
GLMM 1	Word AB Valence				
	Negative vs Neutral	0.20	0.30	0.65	0.514
	Positive vs Neutral	**0.82**	**0.32**	**2.58**	**0.010**
	Word BC Valence				
	Negative vs Neutral	**-0.92**	**0.31**	**-2.94**	**0.003**
	Positive vs Neutral	**-0.82**	**0.29**	**-2.82**	**0.005**
GLMM 2	**Word AB Arousal**	**0.60**	**0.18**	**3.38**	**<0.001**
	Word BC Arousal	**-0.80**	**0.18**	**-4.37**	**<0.001**
GLMM 3	Word AB Valence				
	Negative vs Neutral	-0.24	0.40	-0.61	0.541
	Positive vs Neutral	0.32	0.40	0.80	0.426
	Word AB Arousal	**0.59**	**0.28**	**2.07**	**0.039**
	Word BC Valence				
	Negative vs Neutral	-0.09	0.49	-0.18	0.855
	Positive vs Neutral	-0.17	0.40	-0.44	0.660
	Word BC Arousal	**-0.72**	**0.34**	**-2.14**	**0.033**

Note. Significant effects are shown in bold.

Experimental Study

The results of Analyses of Previous Data showed that the arousal of words influences how Chinese readers segment OASs. However, in the study of Huang et al. (2024), OASs were composed by neutral and emotional words. It remains unclear whether arousal also influences word segmentation when only neutral words are involved. Therefore, we conducted a controlled experiment in which OASs were composed by neutral words AB and BC. The arousal of the words AB and BC were manipulated. If arousal affects word segmentation, word segmentation outcome should vary with the arousal for neutral words. By contrast, if arousal only exerts an effect after word segmentation, word segmentation outcomes should be comparable across different levels of arousal.

Method

Participants. Fifty-nine native Chinese college students (44 females; age range 18–29 years, M = 22.73, SD =2.73) in Beijing were recruited and received monetary compensation for their participation. Five participants were excluded from data analyses because they incorrectly answered more than six among 25 attention-validation items (>25%). All participants had normal or corrected-to-normal vision and no history of mental or language disorder.

To determine the required sample size, we estimated the priori power of the study by using the *powerSim* and *powerCurve* functions of the *simr* package (Green & MacLeod, 2018) within the *R* Environment for Statistical Computing (R Core Team, 2022). First, we analyzed previous data in Huang et al. (2024) using a GLMM, in which the probability of AB-C segmentation was the dependent variable. As an effect of interest to us, the arousal of word BC was entered as the fixed effect. Then, we explored how the power varies as a function of the number of participants. The results indicated that the power estimate of 30 participants was above 95%. To ensure that there were enough participants after exclusion, we recruited 59 participants.

Apparatus. This study was conducted in a quiet room. The stimuli were presented on a 21-inch CRT monitor (Sony Multiscan G520), with a resolution of 1,024 × 768 pixels and a refresh rate of 120 Hz. The experiment was programmed by the E-prime 2.0 software (Psychology Software Tools Inc, Pittsburgh, PA). An OAS was presented in black 40-size Song font on a gray background in the center of the screen.

Stimuli and Design. We chose neutral words with low absolute valence values as stimuli, while orthogonally manipulating the arousal levels of word AB and word BC in the OASs. The experiment was 2 (word AB Arousal: High vs. Low) × 2 (word BC Arousal: High vs. Low) within-subject design. As shown in Figure 2, words with low valence can have either high or low arousal levels. Thus, we could choose enough stimuli for our experiment.

To prepare the stimuli, we selected 100 OASs in total (25 OASs for each condition). We manipulated the arousal of words AB and BC. The frequency, strokes, and valence of words were controlled between different groups (*F*s<1, *p*s>0.05). The arousal at high-arousal level (range from 2.34 to 3.54, M = 2.57, SD = 0.23) was higher than that of low-arousal level (range from 0.71 to 1.43, M = 1.19, SD = 0.14; *t*s > 24, *p*s < 0.001). There was no significant difference when both words were high-arousal words (*t*s < 1.67, *ps* > 0.098) or low-arousal words (*t*s < 1.08, *ps* > 0.282). All the words used in this experiment were at low absolute valence level (range from -0.35 to 0.56, M = 0.14, SD = 0.14). The examples and properties of stimuli are shown in **Table *3***.

Table 3

The Properties and Examples of Stimuli in Experimental Study

Arousal Label	High-High		High-Low		Low-High		Low-Low	
Examples	神秘密		价格式		属性命		化石膏	
Word AB/BC	神秘	秘密	价格	格式	属性	性命	化石	石膏
Translation	Mystery	Secret	Price	Format	Property	Life	Fossil	Gypsum
Frequency	1.13 (0.09)	1.19 (0.10)	1.18 (0.12)	1.12 (0.09)	1.10 (0.07)	1.19 (0.09)	1.17 (0.10)	1.12 (0.09)
Strokes	15.40 (0.65)	15.52 (0.67)	15.16 (0.84)	14.72 (0.67)	14.48 (0.94)	14.92 (0.95)	15.24 (0.74)	15.16 (0.92)
Valence	0.13 (0.03)	0.11 (0.03)	0.11 (0.04)	0.11 (0.02)	0.17 (0.03)	0.16 (0.05)	0.11 (0.03)	0.13 (0.03)
Arousal	2.57 (0.05)	2.61 (0.05)	2.53 (0.03)	1.24 (0.02)	1.15 (0.01)	2.53 (0.04)	1.21 (0.04)	1.20 (0.03)

Note. Arousal Label means "arousal of word AB – arousal of word BC". Standard errors are given in parentheses. The unit of log-transformed frequency is the number of occurrences per million (Lexicon of Common Words in Contemporary Chinese Research Team, 2008). The scores of valence and arousal were derived from the database of Xu et al. (2022).

Procedure. Participants were first provided with instructions, and then finished 20 practice trials to familiarize themselves with the procedure. For each trial, a fixation cross (+) was presented for 500ms first and participants were asked to fixate on the fixation cross. Then, an OAS was presented on screen (the fixation cross and the middle character of OAS were shown at the center of the screen) until response (less than 2,000ms) and participants were asked to indicate the word they identified first by pressing a key on the keyboard (press “D” if they chose word AB; press “K” if they chose word BC). All the trials in which participants did not respond were removed from the data analysis. Finally, a blank screen was presented for 500ms before the next trial was presented. To prevent participants from figuring out the aim of our experiment, a total of 25 attention-validation items (where only one side of stimuli can form a word) and 125 OASs (where both AB and BC of stimuli formed words) composed by middle-level arousal words AB and/or BC (see Appendix **Error! Reference source not found.** for details) were included in the experiment as fillers.

Data Analysis. Participants’ segmentation outcomes and RTs were analyzed using two sets of models. The segmentation outcomes (coding response AB-C as 1 and A-BC as 0) were analyzed using the GLMM with the *R* 4.4 version of the *lme4* package (Bates et al., 2015; R Core Team, 2022). RTs were analyzed using the *linear mixed-effects model* (LMM) using the same R package. The arousal of word AB (High vs. Low), the arousal of word BC (High vs. Low) and their interaction were entered as independent variables. Following Barr et al.’s (2013) suggestion, we constructed a model with the maximal random structure that could converge. We first constructed a model with a maximum random factor structure that specified participants and items as crossed random effects, including intercepts and slopes. When the maximal model failed to converge, we used a zero-correlation parameter model and dropped the random components that generated the minimum variances. We reported regression coefficients (*b*s), *SE*s, *t* values (for RTs) or *z* values (for the segmentation outcomes), and *p*-values of the optimal model (the finally adopted models of the (G)LMM results see **Error! Reference source not found.**).

Results and Discussion

The trials that participants did not make any response and the trials in which RTs were shorter than 200ms were excluded from analyses for the segmentation outcomes. RTs longer than 1,500ms or shorter than 200ms were excluded. Then, RTs beyond three SDs for each condition of each participant were excluded. In total, approximately 1.75% of trials were excluded from the analyses.

Table 4

The Probability of AB-C Segmentation and RTs across Conditions in Experimental Study

	High-High	High-Low	Low-High	Low-Low
Probability of AB-C segmentation	0.44 (0.01)	0.51 (0.01)	0.38 (0.01)	0.52 (0.01)
RT (ms)	721 (5)	739 (6)	729 (6)	725 (6)

Note. Arousal Label means "arousal of word AB **-** arousal of word BC". Standard errors are provided in parentheses.

Table 5

Results of the GLMM for the probability of AB-C segmentation in Experimental Study

Fixed effects	Estimate	SE	*z*	*p*
Word AB arousal	0.11	0.21	0.54	0.591
Word BC arousal	**-0.50**	**0.21**	**-2.39**	**0.017**
Word AB arousal*Word BC arousal	0.46	0.42	1.09	0.276

Note. Significant effects are shown in bold.

As shown in Tables 4 and 5, the main effect of word BC arousal was significant. The probability of AB-C segmentation of high-arousal word BC (M = 0.41, SE = 0.01) was lower than that of low-arousal word BC (M = 0.51, SE = 0.01). The main effect of word AB arousal and the interaction between word AB arousal and word BC arousal were not significant.

These findings suggest that arousal of words affect Chinese word segmentation for neutral words. Specifically, the high-arousal word BC increased the probability of segmenting OAS as A-BC. Word BC with high arousal may be activated stronger, making it more likely to win the competition with word AB and hence be segmented.

None of the results were significant for RTs analyses (ps > 0.10; see **Error! Reference source not found.** for details). Because participants were not explicitly asked to respond as quickly as possible, the RT data may provide limited information about word segmentation process. Indeed, previous studies using similar paradigms have not reported any effect on RT (Chen et al., 2024).

General Discussion

The present study examined the effect of arousal on Chinese word segmentation. The reanalysis of the data from Huang et al. (2024) indicated that arousal exerted effects on word segmentation, with higher-arousal words more likely to be segmented. In the experimental study, we controlled the valence of words so that they were all neutral word, while manipulating their arousal levels. The results revealed that the high-arousal word BC increased the probability of segmenting OAS as A-BC compared to the low-arousal word BC.

The significant effect of arousal on word segmentation outcome supports the view that arousal can affect Chinese word segmentation, but contradicts the view that arousal exerts an effect only after words are segmented. According to the CRM, once a word wins the word competition, it is identified and segmented simultaneously. If arousal of words is activated only after segmentation, it has no chance to affect word competition and hence the word segmentation outcome. Thus, word segmentation outcome should not vary with different levels of arousal.

However, our results suggest that regardless of emotional or neutral words, words with higher arousal levels were more likely to be segmented. These findings indicate that arousal of words might be activated along with the activation of word units and provide feedback to the word level. This feedback enhances the activation of corresponding word units, making them more likely to win the competition and hence be segmented.

These findings contribute to understanding the time course of arousal effects on word processing. Previous studies have shown that arousal has a monotonic effect on lexical decision latencies, but it remains unclear at what stage arousal exerts its effect (Kuperman et al., 2014). Specifically, arousal may influence either the early stage of activating a word's representation or the later stage of making a response (Yap & Seow, 2014). The observed effect of arousal on word segmentation provides evidence that arousal impacts the early stage of word processing, especially the activation of word representations.

The effect of arousal was observed only for word BC in the experimental study which only involved neutral words. A potential explanation is that the impact of arousal on word segmentation might be modulated by attention allocation, which is influenced by reading direction and fixation position. Chinese readers are familiar with reading from left to right in natural reading, so they tend to allocate more attention to the words on the right side of fixation (Liu et al., 2020). In the present study, participants were asked to fixate on the middle character B of OASs, so they tended to allocate more attention to word BC. As a result, the arousal of word AB might not be sufficiently activated to influence word segmentation. Thus, the arousal effect was found for word BC but not for word AB. The observed positional advantage of right-side word is supported by previous studies using the same method of string presentation and asking fixation at the center of OASs (Chen et al., 2024; Ma et al., 2014. Experiment 1).

The results of our study are suggestive for future studies on emotional-word processing. Future studies should carefully consider the potential confounding effect of arousal when comparing emotional and neutral words. Most previous studies have compared emotional words with neutral words, but emotional words often have higher arousal than neutral words (as shown in Figure 2), raising the possibility that the observed processing advantages of emotional words over neutral words (e.g., Kousta et al., 2009) might be confounded by arousal. Our results demonstrate that arousal alone can influence processing, suggesting that future research should control for arousal when comparing emotional and neutral words.

The present findings have limitations. First, we used isolated OASs rather than embedding them in sentences to investigate arousal effects on Chinese word segmentation. This was motivated by the limited number of OASs formed by words with different levels of arousal that can naturally appear in sentences. Using isolated OAS allowed sufficient experimental stimuli for a powerful examination. Although the isolated OAS segmentation task is not exactly the same as word segmentation in sentence reading, previous studies using this paradigm have provided valuable insights into the cognitive processes underlying Chinese reading (Chen et al., 2024; Huang et al., 2024; Liu et al., 2023; Ma et al., 2014). Our findings using the OAS segmentation task also contribute to the understanding of Chinese reading, suggesting that Chinese readers can utilize arousal to help with Chinese word segmentation. Future research could investigate whether the observed arousal effects generalize to more ecologically valid reading tasks. Second, future studies should include more attention-validation items to reduce task-induced strategies. In the present study, we included 25 attention-validation items and 125 filler OASs composed of middle-level arousal words to prevent participants from figuring out the aim of our experiment. Critical stimuli occupied only 40% of the total trials, likely reducing strategy use, but additional attention-validation items could further improve experimental control.

In conclusion, the results of the present study provide evidence that the arousal of words can affect Chinese word segmentation, with higher-arousal words being more likely to be segmented than low-arousal words. These results highlight the importance of considering word arousal into models of Chinese reading. Moreover, our findings are also essential for understanding the impact of arousal on word processing and suggest that it impacts the early stage of activating a word's representation.

Declaration

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Conflict of interest statement

The authors declare no conflicts of interest.

Data availability statement

The data, code and materials of this study are publicly available at Open Science Framework website and can be accessed at https://osf.io/dhqgj/files/osfstorage?view_only=6f89b0db819342618190fcb8664f69c7

Code availability

The code is available from https://osf.io/dhqgj/files/osfstorage?view_only=6f89b0db819342618190fcb8664f69c7

Ethics approval

The study was approved by the ethics committee of [anonymized source].

Consent to participate

All participants gave their informed consent prior to their inclusion in the study.

Consent for publication

The participant has consented to the submission of their data to the journal.

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Appendix A: Supplementary Analysis for Analyses of Previous Data

Table A1

Results of the GLMM for the Probability of AB-C Segmentation for All Items

Model	Fixed effects	Estimate	SE	*z*	*p*
GLMM 1	**Word AB Valence**				
	Positive vs Neutral	**0.83**	**0.28**	**2.95**	**0.003**
	Negative vs Neutral	0.27	0.30	0.91	0.364
	Word BC Valence				
	Positive vs Neutral	**-0.78**	**0.28**	**-2.80**	**0.005**
	Negative vs Neutral	**-1.02**	**0.28**	**-3.61**	**<0.001**
GLMM 2	**Word AB Arousal**	**0.61**	**0.17**	**3.64**	**<0.001**
	Word BC Arousal	**-0.83**	**0.18**	**-4.71**	**<0.001**
GLMM 3	Word AB Valence				
	Positive vs Neutral	0.45	0.36	1.25	0.210
	Negative vs Neutral	-0.11	0.38	-0.28	0.778
	Word AB Arousal	**0.48**	**0.26**	**1.83**	**0.067**
	Word BC Valence				
	Positive vs Neutral	-0.33	0.37	-0.88	0.378
	Negative vs Neutral	-0.52	0.44	-1.19	0.234
	Word BC Arousal	**-0.51**	**0.30**	**-1.68**	**0.093**

Note. Significant effects are shown in bold.

Table A2

Final Generalized Linear Mixed-effects Models

Section	Model	Formula
Analyses of Previous Data	GLMM 1	Prob~ word AB valence + word BC valence + (1+ word AB valence (positive vs neutral) + word AB valence (negative vs neutral) + word BC valence (positive vs neutral) + word BC valence (negative vs neutral) ||SUB) + (1+ word AB valence (negative vs neutral) + word BC valence (negative vs neutral) ||ITEM)
	GLMM 2	Prob~ word AB arousal + word BC arousal + (1+ word AB arousal + word BC arousal ||SUB) + (1|ITEM)
	GLMM 3	Prob~ word AB valence + word BC valence + word AB arousal + word BC arousal + (1+ word AB valence (positive vs neutral) + word AB valence (negative vs neutral) + word BC valence (positive vs neutral) + word BC valence (negative vs neutral) + word AB arousal + word BC arousal ||SUB) + (1|ITEM)
Analyses of all items	GLMM 1	Prob~ word AB valence + word BC valence + (1+ word AB valence (positive vs neutral) + word AB valence (negative vs neutral) + word BC valence (positive vs neutral) + word BC valence (negative vs neutral) ||SUB) + (1+ word AB valence (negative vs neutral) + word BC valence (negative vs neutral) ||ITEM)
	GLMM 2	Prob~ word AB arousal + word BC arousal + (1+ word AB arousal + word BC arousal ||SUB) + (1|ITEM)
	GLMM 3	Prob~ word AB valence + word BC valence + word AB arousal + word BC arousal + (1+ word AB valence (positive vs neutral) + word AB valence (negative vs neutral) + word BC valence (positive vs neutral) + word BC valence (negative vs neutral) + word BC arousal ||SUB) + (1+ word AB valence (negative vs neutral) + word BC valence (negative vs neutral) ||ITEM)

Note. Prob = the probability of AB-C segmentation. Valence is a three-level variable, we defined neutral word as baseline and detected the *positive vs neutral* and *negative vs neutral* contrast.

Appendix B: Supplementary Materials for Experimental study

Table B1

The Properties of Middle-Arousal Fillers in Experimental Study

Arousal Label		High-Middle	Low-Middle	Middle-High	Middle-Low	Middle-Middle
Word AB	Frequency	1.18(0.08)	1.15(0.13)	1.16(0.09)	1.18(0.11)	1.14(0.04)
	Strokes	15.52(0.76)	15.16(0.76)	15.24(0.83)	14.72(0.66)	15.80(0.82)
	Valence	0.11(0.04)	0.12(0.04)	0.11(0.04)	0.12(0.03)	0.14(0.03)
	Arousal	2.62(0.05)	1.16(0.02)	2.01(0.03)	2.03(0.04)	2.08(0.03)
Word BC	Frequency	1.16(0.11)	1.11(0.13)	1.17(0.11)	1.17(0.10)	1.16(0.07)
	Strokes	15.76(0.81)	14.84(0.72)	15.16(0.74)	14.48(0.58)	15.92(0.66)
	Valence	0.19(0.03)	0.17(0.04)	0.14(0.03)	0.11(0.03)	0.13(0.03)
	Arousal	2.05(0.03)	2.01(0.03)	2.60(0.05)	1.18(0.03)	2.05(0.03)

Note. Arousal Label means "arousal of word AB – arousal of word BC". Standard errors are given in parentheses; The unit of log-transformed frequency is the number of occurrences per million (Lexicon of Common Words in Contemporary Chinese Research Team, 2008); The scores of valence and arousal were based on the database of Xu et al. (2022).

The frequency, strokes, and valence of words were controlled between different groups (Fs<1, ps>0.05). The arousal at high-arousal level (range from 2.35 to 3.33, M = 2.61, SD = 0.24) was higher than that of middle-arousal level (range from 1.80 to 2.33, M = 2.04, SD = 0.16; ts > 10.65, ps < 0.001). The arousal at middle-arousal level was higher than that of low-arousal level (range from 0.74 to 1.35, M = 1.17, SD = 0.13; ts > 17.17, ps < 0.001). There was no significant difference when both words were middle-arousal words (ts < 1.43, ps > 0.156).

Table B2

Results of Linear Mixed-effects Models for RTs

Fixed effects	Estimate	SE	*t*	*p*
Word AB arousal	<0.01	0.01	0.33	0.739
Word BC arousal	-0.01	0.01	-0.51	0.612
Word AB arousal*Word BC arousal	-0.03	0.02	-1.23	0.221

Table B3

Final (Generalized) Linear Mixed-effects Models

Model	Formula
GLMM	Prob~ word AB arousal*word BC arousal + (1 + word AB arousal*word BC arousal ||SUB) + (1 + word AB arousal + word BC arousal + word AB arousal*word BC arousal ||ITEM)
LMM	log(RT)~ word AB arousal*word BC arousal + (1 + word AB arousal + word BC arousal + word AB arousal*word BC arousal ||SUB) + (-1 + word AB arousal + word BC arousal + word AB arousal*word BC arousal ||ITEM)

Note. Prob = the probability of AB-C segmentation