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Introduction

Recognition of a visually presented word requires extracting the visual features from the word's retina image as the first step. However, encoding the visual information of word is restricted by the density distribution of retinal receptors, in which the visual acuity drops rapidly outside the fixating location. Even in the foveal region, visual acuity reduces to about 60% of maximum at an eccentricity of one degree (Brysbaert & Nazir, 2005). In consequence a reader tends to move eyes to fixate on words to receive high quality image on the retina. Moreover, in the foveal visual field, the information at different positions of a word is not visible in the same quality. In such situation, the best strategy to identify a word is fixating at the location where can maximize the useful information covered by the small region of high visual acuity.

The drop of visual acuity away from fixation implies that word recognition depends on the fixating position within word. This argument is supported by showing that there is a location in a word where the recognition time is minimized, referred as the optimal viewing position (OVP) (O'Regan & Levy-Schoen, 1987). Many studies have investigated the OVP effect by the manipulation of the initial fixation position within a word, using the tasks of word naming (O'Regan & Jacobs, 1992; O'Regan, Levy-Schoen, Pynte, & Brugaillere, 1984), lexical decision (Nazir, O'Regan, & Jacobs, 1991; O'Regan & Jacobs, 1992), and perceptual identification (Brysbaert, Vitu, & Schroyens, 1996; Nazir, Heller, & Sussmann, 1992; Stevens & Grainger, 2003). The results consistently showed that the initial fixation curve of recognition time or error rate is U-shaped and typically the OVP is a bit left to the center of the word.

The U-shaped curve of recognition performance across letter positions indicates that recognition difficulty increases as a function of viewing positions in the word. Since letters further from fixation are less well represented peripherally, the ease of word identification at different fixation position can be estimated by letter perceptibility. In a summed letter information model (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989), the hypothetical word identifiability is the sum of individual letter visibilities, which are calculated according to the distance between the letter position and the initial fixation position. It successfully predicts the viewing position effects of word recognition which is caused by the visibilities of component letters.

However, the asymmetry of the viewing position curve is out of the symmetric prediction simply based on visual acuity. The asymmetry of hemifield acuity has been reported in individual letter perceptibility to account for the asymmetry of the OVP effect (Nazir et al., 1992; Nazir et al., 1991). For example, Nazir et al. (1991) demonstrated that the letter visibility falls away 1.8 times more sharply in the left visual field (LVF) than the right visual field (RVF). However, this RVF advantage can also result from the influence of other factors, likes hemispheric asymmetry and information structure of words. Moreover, a recent study showed a highly symmetrical inverse U curve of letter perceptibility as a function of viewing position (Stevens & Grainger, 2003). Regarding the variation of letter visibility to word eccentricity, it provides weak evidence to explain the asymmetry of the OVP effects.

In addition to letter perceptibility, there are several factors has been suggested to account for the asymmetry, including perceptual learning, hemispheric asymmetry, and the information profile of words (Brysbaert & Nazir, 2005; Rayner, 1998). Perceptual learning refers that the ability to discriminate a target can improve by training of presenting similar stimuli repeatedly at particular position in the visual field (Nazir &

O'Regan, 1990). In reading, the statistics about where the eyes tend to land in a natural reading situation according to the reader's experience are critical for retinal training. The landing site distribution can represent the frequency of which words are processed from different locations on the retina (Nazir, Ben-Boutayab, Decoppet, Deutsch, & Frost, 2004). For left-right alphabetic languages, there is a tendency to fixate between the beginning and the middle of the words, referred as the preferred landing position (PLP) (McConkie, Kerr, Reddix, & Zola, 1988; Rayner, 1979). The PLP is mainly determined by the low-level visual and oculormotor factors (Rayner, 1998). Given the observation of that the fixations land on word beginning more frequently than on word ending, word information are processed more efficiency at the PLP. Therefore the recognition performance would show the RVF advantage. The asymmetric OVP effects can reflect the frequency of the training on the retina. It should be noted that, the PLP in Hebrew which is a right-left script has been shown at the right of center (Deutsch & Rayner, 1999). However, the OVP curve for right-left scripts (Hebrew and Arabic) is much more symmetric (Farid & Grainger, 1996; Nazir et al., 2004) than the left-right scripts (English and French). This implies, in addition to perceptual learning, there are other factors contributing in the asymmetry OVP effects.

In addition to the factors aforementioned, lexical structure of words also play an important role to account for the asymmetry of viewing position curve. It highlights the nature of how the lexical processing system encodes the information at different letter positions. As long as a reader recognizes more words in reading experience, the statistics of the learned words about the probability of a letter or letter string appearing in a word can be obtained. This provides an objective method to estimate the ease of identifying any word on the basis of the partial word information, which is perceived from letter positions with the best visual acuity. The information profile of words can serve as the probabilistic principles which are acquired from lexical knowledge to determine the OVP for word recognition. One source of the information is the entropy on a given position, referring the extent of variance about the information carried on a letter position. The other source is the lexical constraint, referring the probability to recognize a word from the partial word information with high resolution perceived from a fixating position.

In a connectionist model of reading, the entropy values for letter positions in words represent the processing difficulty (Monaghan, Shillcock, & McDonald, 2004). The higher the entropy value for a letter position is, the more information the position carries. The entropy for every letter position in the range of hypothetic reading span could be estimated from all the words with the same length. Monaghan et al. (2004) reported that, in English, the letters at the left side are more varied than those at the right side. This implies the information distribution of letters in words in the lexicon is asymmetric. The OVP at the left of words could be because of the processing efficiency by projecting the denser information with highest resolution.

The second source of the information profile of words is lexical constraint, reflecting the ease of identifying a word from one or several constituent letters. As more letters of a word are available, the ambiguity of the word is reduced. An analysis of French corpus has shown that more words shared the same final letters than the same initial letters (O'Regan et al., 1984). Clark and O’Regan (1999) proposed a simple four-letter coding model to estimate word ambiguity when two outer letters and two letters near to fixation were known. They performed a statistical analysis of English and French corpuses to obtain word ambiguity as a function of fixation. The plots of ambiguity measurements showed the asymmetry to the left of word center which were similar to empirical viewing position curves. Stevens and Grainger (2003) combined the measures of letter visibility and ambiguity successfully predicted the empirical OVP results of words. Therefore the left-shifted OVP reflects the best position where has the benefit to allow the least ambiguous letters to be projected on foveal region.

Research directly manipulated the lexical informative of words and found the OVP was at the initial letters when words had unique beginning (Brysbaert et al., 1996; O'Regan & Levy-Schoen, 1987; O'Regan et al., 1984). These studies also showed that the OVP did not be pulled to the opposite side for words with unique ending comparing with unique beginning. It is clear that lexical constraint can influence the OVP effects for some extent. However it interplays with other factors to determine the OVP (Brysbaert & Nazir, 2005; Stevens & Grainger, 2003). One study using Arabic words with different morphological structure showed a reversal in the asymmetry (Farid & Grainger, 1996). They found that the OVP was at the word ending for prefixed word compared with suffixed words. It should be pointed out that Arabic suffixed words actually showed a symmetry OVP curve. These studies consistently demonstrated that the influence of lexical constraint is asymmetry.

Shillcock, Ellison, and Monaghan (2000) proposed a hemispheric processing model of word recognition and the informative distribution of words was taken into account. They argued that, based on the split fovea claim (Lavidor & Walsh, 2004), the OVP phenomenon in English word recognition revealed an optimal division of labor between the two hemispheres. More specifically, they proposed an algorithm to calculate the optimal splitting point of words in a lexicon, aiming at giving both sides equal probability of identifying the word and maximizing the sum of information on both sides. Their modeling results reflected the fact that the beginning of English words tend to be more informative than the endings, and also resembled the OVP observed in human data (O'Regan, 1990). The results also captured the hypothesis that the distributions of optimal split points for words with more informative beginnings and endings are asymmetrical (O'Regan & Levy-Schoen, 1987): there was a small rightward shift of the OVP for end-informative words.

Moreover, the anatomic constraint of fovea splitting suggests that the word information split by the fixation is projected to different hemispheres. This provides the ground to explore the possible hemispheric asymmetry of information processing. Recently, Shillcock and his colleague used the split fovea framework to simulate the OVP effect (Shillcock & Monaghan, in prep.). They reported that lateralization of computational resources within the model (i.e., giving more hidden units to one “hemisphere” of the model) is very effective in skewing the curve to produce the classic shape of the OVP curve.

The considerable research carried out on the OVP effect has variously suggested the roles for hemispheric processing differences, information structure of the words in the lexicon, reading experience, and letter visibility as a function of eccentricity. These factors may have interactions to decide the best letter position for word recognition (see Brysbaert & Nazir, for a review, 2005). The goal of the project is to examine whether the viewing position curve of Chinese word recognition is also asymmetric and how different factors can account for the OVP effect.

There are some features of lexical structure for Chinese written system which are different from alphabetic languages. For reading Chinese, characters are the perceptually prominent units and they usually are also syllables and morphemes. In text the great majority of the characters are actually constituents of compound words rather than being individual words. For these compounds, character meanings are not always transparent to word meaning. According to the Chinese word corpus of Academia Sinica Taiwan (1998), the proportion of one-, two-, three-, and four-character words are 9.5%, 65.6%, 12.4%, and 11.6%, respectively. As the consequence, words with various lengths are mixed in a sentence. However, there is no perceptual indicator of where words begin and end when reading a sentence. It calls into the question of whether word or character is the reading unit and how the ‘where’ decision of eye movements can be made in the reading of Chinese.

In reading text, Chinese reader show no preferred landing position on words (Tsai & McConkie, 2003; Yang & McConkie, 1999). Tsai and McConkie (2003) reported that the landing position curve was relatively flat on two-character words, compared with English 7-letter words with the same visual angle. A further regression analysis showed that both character and word frequency of one to two characters next to the current fixation affect the probability of landing on that character position. Another study also showed both character frequency and word frequency effects for fixation time in reading sentences (Yan, Tian, Bai, & Rayner, 2006). These findings imply that word processing plays a role in making eye movement decisions but character processing also has its influence.

Word recognition involves hierarchical processing of sub-lexical units. For example, words in alphabetic scripts are composed of letters and Chinese words are composed of characters, which can be further decomposed into radicals. The order or the configuration of these sub-lexical units can distinguish different words / characters (e.g., act, cat, and cap are different words; 國中 ‘junior high school’ and 中國 ‘China’ are different words; 部 ‘part’ and 陪 ‘to accompany’ are different characters). In addition, letters at different positions (such as initial or final) seem to contribute differently to word recognition. It has been shown that initial letters provide more lexical constraint than final letters (Farid & Grainger, 1996). For example, if the initial letters of a 5-letter word are available (such as FABL_), FABLE is the only candidate word. On the other hand, if the final letters of the same word are available (i.e., _ABLE), there are many candidates (such as CABLE, TABLE, FABLE). Clark and O’Regan (1999) calculated an ambiguity measure, in which numbers of candidate words were computed given two consecutive internal letters at various positions and the two exterior letters. They found that for words that contain 5 to 11 letters, the ambiguity was the lowest when a two-letter pair to the left of word center was available. These findings suggest that initial letters and those around word center are constraining.

Fraid and Grainger (1996) investigated the causes for the OVP by manipulating lexical constraint and reading direction. In their study, French (read from left to right) and Arabic (read from right to left) were compared. In addition, affixed words were chosen as the material. For prefixed words, the initial letters (i.e., the prefixes) are less constraining than the final letters. In contrast, for suffixed words, the initial letters are more constraining than the final letters (i.e., suffixes). Overall, the curve for Arabic words was symmetric but it depended on the morphological structure. The OVP on prefixed Arabic words was at word ending while that on suffixed words was at word beginning. In contrast, the OVP on French words was generally to the left of word center, with this leftward asymmetry more evident for suffixed words. Thus, depending on the writing system, one factor is more important than the others for the OVP. For example, morphology seems to play a dominant role in recognizing Arabic words.

Besides clarifying the mechanism for the OVP in word recognition, OVP can be used as a tool to investigate how sub-lexical units contribute to word processing. The present project aimed to investigate the influence of the information profile of sub-lexical units (constituent characters and radicals) on Chinese word and character processing by observing the OVP curve.

In Years 1 and 2, the OVP on words was observed when the informativeness of both constituent characters were either matched or varied naturally. Specifically, in Year

1, the OVP curve on isolated two-character words was observed with the lexical decision task. In Year 2, the OVP curve on words (especially two- and three-character words) was observed during normal passage reading. Since there are no visual cues for word boundaries in Chinese sentences, the contribution of a potential statistical cue (i.e., the probability of each character being used as word beginning/ending) to word recognition in continuous text reading was examined. In Year 3, the influence of sub-lexical information profile on word/character recognition was investigated. In Experiment 3-1, neighborhood sizes (defined later) of both constituent characters of two-character words were manipulated orthogonally in addition to the manipulation of fixation positions. If these factors play a role in word recognition, they may influence the OVP. Similarly, in Experiment 3-2, the effects of radical combinability on character recognition was investigated by simultaneously manipulating both the semantic and phonetic radicals.

Year 1: OVP on Words (Lexical Decision Task)

Method

Participants. Twenty-eight male university students at National Yang-Ming University were paid to participate in this experiment. All of them are native speakers of Chinese with normal or corrected-to-normal vision and right-handed.

Design and Materials. A list of 140 Chinese two-character words was used as the stimuli. Word frequencies were controlled in the range of 10 to 100 per million (with an average of 35.54 occurrences per million). The lexical properties of the first and second constituent characters, including number of strokes (11.5 vs. 11.4), subjective familiarity (5.3 vs. 5.4), and word combinability (12.3 vs. 12.0), were matched for all words. The subjective familiarity is based on an unpublished corpus of 5640 Chinese characters. The data were collected from 160 college students by using a 7-point scale for familiarity rating. Word combinability measure was obtained from the corpus by calculating number of two-character words sharing the same first or second constituent character. In addition, 140 pseudowords were created for the lexical decision task. The lexical properties of their constituent characters were matched to those of real words.

Stimulus position was manipulated so that each time a stimulus was presented in one of the seven positions: on the half character position in front of the word (as position -3), on the left half of the first character (as position -2), on the right half of the first character (as position -1), on the middle of the word (as position 0), on the left half of the second character (as position 1), on the right half of the second character (as position 2), and on the half character position behind the word (as position 3). It should be noted that in the position -3 and 3 conditions, the whole character string was presented out of the fixation point, either in the RVF or LVF. The words and pseudowords were randomly divided into 14 lists of twenty words. The lists were distributed over the seven possible display positions according to a Latin square table so that each list was seen in each condition every seven participants.

Apparatus. A video-based eyetracker (iView X Hi-Speed System by SensoMotoric Instruments, Germany) was used to ensure that the eyes of participants were fixating exactly on the central position in each trial. The sampling rate was 500 Hz. The reading material was displayed on a ViewSonic G90fB monitor. The stimuli were presented one at a time for 100 ms in isolation at the center of the display screen and appeared white in a dark background. The size of each character of the two-character string was 40 pixels in the resolution of 1024 x 768 pixels The viewing distance was 80 cm and the width of two-character strings subtended approximately 2.1° of visual angle.

Procedure. In the beginning of the experiment, a nine-point calibration procedure was used for each participant to determine the correspondence between pupil position and gaze position. At the beginning of each trial, a fixation plus sign '＋' (10*10 pixels) appeared at the center of the screen, and participants were asked to fixate at the center of the plus sign. Once the gaze position remained fixating at the central position (within a range of 5 pixels) for 60 ms, the stimulus was presented at any of the seven positions (positions -3 to 3) for 100ms and followed by a blank screen. Participants were requested to decide whether the stimulus was a 'word' or 'nonword' by pressing the assigned buttons on the response pad (RB-830 by Cedrus Corporation, USA). Positive responses were made with both index fingers, and negative responses with both middle fingers. The participants were instructed to respond as rapidly and accurately as possible. A total of 280 trials were separated into 5 blocks to be completed in the experiment.

Results

Only correct responses were analyzed with regard to reaction time, which was further restricted to be less than 2000 ms. The reaction time and error rates as a function of viewing positions were shown in Figures 1 and 2. An analysis of variance (ANOVA) was performed on reaction time of words with initial fixation position as the within-subject factor. The main effect of fixation position was significant [$F(6,162) = 13.10$, $p < .05$). Post hoc analysis further revealed that position 0 was significantly different from all other positions (ps < .05) except for positions 1 and -1 (ps > .22). Position 1 was significantly different from all other positions (ps < .05) except for position 0. It is worth noting that position 1 had the fastest reaction time 625 ms and it was significantly different from position -1 ($p < .05$). Position 3 had the slowest reaction time 680 ms and it was significantly different from all other positions except for position -3. An analysis of variance (ANOVA) was also performed on error rates of words with initial fixation position as the within-subject factor. The main effect of fixation position was significant ($F(6,162) = 6.09$, $p < .05$). Post hoc analysis showed that position 7 had the highest error rate 8.04% and was significantly different from all other positions (ps <.01). No other comparisons were significantly different.

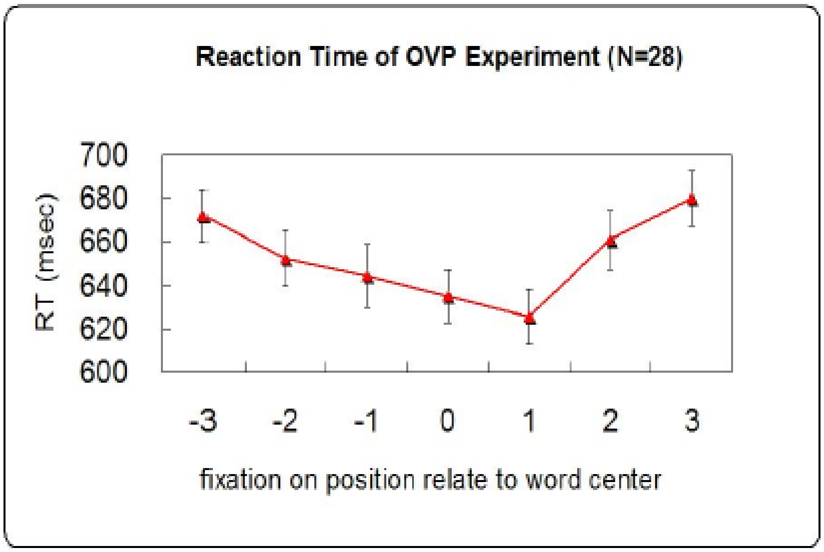

Figure 1: Mean reaction time as a function of initial fixation position.

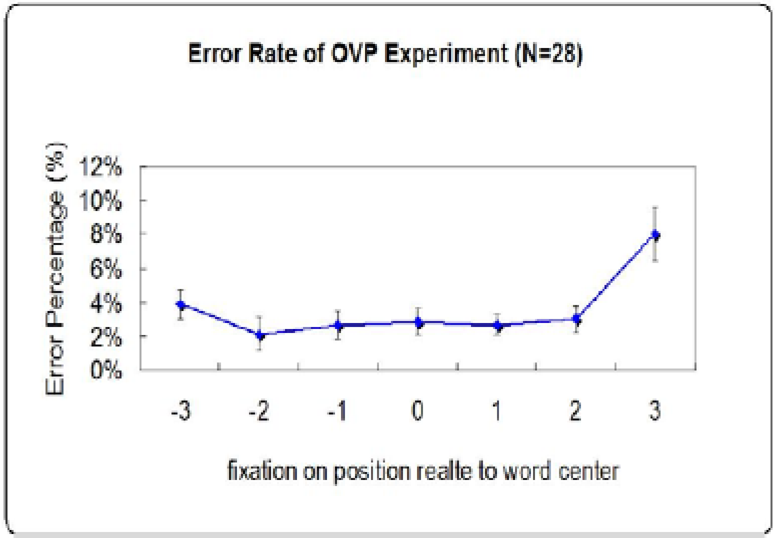

Figure 2: Mean percentage of incorrect responses to words as a function of initial fixation position.

Discussion

This experiment showed that response latencies of lexical decision increased when words presented away from the fixation location. Moreover, the optimal viewing position was at the first half of the ending character, which is to the right of the word center. The rightward asymmetric OVP curve cannot be easily explained by reading direction or hemispheric asymmetry of language processing. One possible explanation for the right-shifted OVP is the reading strategy developed in the normal reading situation. For Chinese readers, fixating on the second character may be more efficient to know where a word is because of the lack of word boundary information in Chinese sentences. Another explanation can be provided by analyzing the lexical information distribution on different character positions.

We conducted a complementary analysis on a corpus of 4,020,000 Chinese two-character words (35,673 words in type) to explore the information profile on different character positions (Table 1). The results indicated that the entropy on the first character position is a bit higher than that on the second character position. However, the OVP found here was not on the position where was more informative. When word combinability at different character position was considered, a smaller set of characters in the second character position can be the constituent of 50% word types or tokens in the corpus. Thus, fixating on the second character of word can increase the possibility to have more activation from similar words. We speculate that the tendency to fixate on the second character might have the advantage to determine whether the character string is a word or not in the lexical decision task.

Table 1: The properties of lexical information distribution over two-character words calculated from the Academia Sinica Balanced Corpus

character Position	No. of char. (type)	Entropy (token freq.)	Combinability/Neighborhood Size		
			Mean N	Min. chars. for 50% word type	Min. chars. for 50% word token
1st Char.	3908	9.60	9.13	462	301
2nd Char.	3655	9.47	9.76	360	259

Shillcock, Ellison, and Monaghan (2000) proposed a hemispheric processing model of word recognition and the informative distribution of words was taken into account. They argued that, based on the split fovea claim (Lavidor & Walsh, 2004), the OVP phenomenon in English word recognition revealed an optimal division of labor between the two hemispheres. More specifically, they proposed an algorithm to calculate the optimal splitting point of words in a lexicon, aiming at giving both sides equal probability of identifying the word and maximizing the sum of information on both sides. Their modeling results reflected the fact that the beginning of English words tend to be more informative than the endings, and also resembled the OVP observed in human data (O'Regan, 1990). The results also captured the hypothesis that the distributions of optimal split points for words with more informative beginnings and endings are asymmetrical (O'Regan & Levy-Schoen, 1987): there was a small rightward shift of the OVP for end-informative words.

Experiment 1 in Year 3 was designed to investigate whether lexical constraint can have a direct influence on the OVP by manipulating word combinability at different character positions. In Year 2, the OVP on words during normal passage reading was examined.

Year 2: OVP on Words (Normal Passage Reading)

Chinese sentences are written character-by-character without explicit cues for word boundaries. Probabilities of a character being used as word beginning/ending may be useful statistical cues to identify a word embedded in a series of characters. The OVP of a word during text reading can be inferred from the trough of the curve of refixation probability as a function of initial landing position (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989). It is found that during text reading with alphabetic scripts, refixation probability was the lowest when participants initially fixated to the left of the word center, which is similar to the OVP observed in lexical decision and naming tasks. In the present experiment, the OVP on 2-character words during passage reading and the contribution of information profile within word (in terms of the probability of a character being used as word beginning/ending) was investigated.

Method

Participants. Forty-eight college and graduate students at National Yang-Ming University and National Chengchi University were paid to participate in this experiment. All of them are native speakers of Chinese with normal or corrected-to-normal vision.

Materials. Participants read four passages selected from magazines for comprehension. Each passage contained 2008 characters on average (1883 ~ 2163 characters), with each punctuation mark occupying a character space. There were totally 3768 words in the passages, each of which contained 942 words on average. The proportion of words for lengths 1, 2 and more than 2 characters are: 52.1%, 42.5% and 5.5%. The order of four passages was counterbalanced with Latin square assignment.

The probability of a character being used as word beginning/ending was calculated from Academia Sinica balanced corpus (Academia Sinica Taiwan, 1998), which contains more than 9000 segmented passages. Because 2-character words are frequently used, the analysis was restricted to 2-character words. Three types of probabilities of a character being used as word beginning/ending were calculated. First, number of 2-character words in which a particular character is used as word beginning was calculated. Similarly, number of 2-character words in which this character is used as word ending was calculated. Dividing by number of 2-character words that contain this character at either position, the proportion that this character is used as the beginning or ending of 2-character words was calculated. This calculation considered type frequencies. Second, instead of counting number of 2-character words that contain a particular character, the sum of frequencies of these words was used. The probability that a character is used as word beginning/ending was calculated in the similar way as the first calculation, except that token frequencies were considered in the second calculation. Third, sum of frequencies of words, regardless of word length, that contain a particular character was calculated. That is, the denominator was the sum of all words that contain the character. The probability of a character being used as the beginning/ending of 2-character words was calculated in the similar way as the second calculation except that different denominator was used.

Apparatus. Similar to that of Year 1, eye movements were recorded by an iView X Hi-Speed eye tracker and the sampling rate was 500 Hz. The characters were shown in black on a light gray background. All passages were arranged to have 22 characters per line and 4 (horizontal) lines per page. There were totally 93 pages, with 22 to 25 pages per passage. The size of a character was 32 × 32 pixels. The space between characters was 4 pixels and the space between lines was 50 pixels. The viewing distance was 74 cm, at which each character subtended 0.81°.

Procedure. Participants were instructed to read normally for comprehension. They were told that there would be four comprehension questions after reading each passage. After a 13-point calibration and verification for calibration accuracy, a practice passage (4 pages) and two comprehension questions were given.

The experimental phase started with the calibration procedure. Participants read each passage page by page. Before each page, participants were instructed to fixate on a cross presented at the position of the first character (top left). The experimenter pressed a button to accept this calibration check or to recalibrate. Then, participants read the page at their own pace and pressed a button when they finished reading this page. Four yes/no comprehension questions were presented at the end of each passage. Feedback on their responses was given. Participants could take a break after answering the comprehension questions. The next passage started with the calibration procedure. The experiment lasted about 40 minutes to 1 hour.

Results and Discussion

First-pass fixations on words that contain 1 to 3 characters in the four passages were selected for further analysis. First and last words on each line were excluded from analysis. In addition, fixations interrupted by blinks, before and after line crossing (due to oculomotor errors, processing difficulty or after finishing reading each line) were excluded from analysis. Initial landing position (i.e. preferred viewing location, PVL; Rayner, 1979) and refixation probability on words that contain 1 to 3 characters were calculated to find the OVP during text reading. Then, gaze durations (GD) on 2-character words were calculated. This measure is the sum of durations of all first-pass fixations (independent of number of fixations) on a word before leaving it. The contribution of the probability of a character being used as word beginning/ending to word recognition and OVP was examined.

Initial Landing Position and Refixation Probability. Initial landing position on a word was calculated as character position from the word beginning. The space prior to each character was included in calculation. For instance, 1.3 means the participant fixated slightly to the left of the center of the second character of the word. Separately for 1-, 2-, 3-character words, distribution of the initial landing positions (on each half-character) is presented in Figure 3. Separate one-way ANOVA was conducted for each word length. There was no difference in the proportion of landing on either half of a 1-character word (49.9 and 50.1%), $F < 1$. For 2-character words, the difference in the proportion of landing on each half-character (24.7, 25.6, 26.1, and 23.5%) was significant, $F(3,141) = 6.71$, $p < .001$. There was a significant quadratic trend, $F(1,47) = 17.75$, $p < .001$. The linear trend was not significant, $F < 2$, $p > .21$. Post-hoc pair comparisons showed that the probability of landing on word ending (1.75) was significantly lower than the middle of the word (0.75 and 1.25), *p*s < .05. For 3-character words, there was a significant main effect of landing position (18.9, 19.2, 19.6, 17.8, 14.3, and 10.3%), $F(5,235) = 13.99$, $p < .001$. Both the linear and quadratic trends were significant, $F(1,47) = 32.17$, $p < .001$ and $F(1,47) = 22.23$, $p < .001$, respectively. Post-hoc pair comparisons showed that probabilities of landing on the initial three positions (0.25, 0.75 and 1.25) were significantly higher than those of landing on the last two positions (2.25 and 2.75), all *p*s < .05. The probability of landing on the last position (2.75) was also significantly lower than those of landing on the fourth and fifth positions (1.75 and 2.25), both *p*s < .01. The difference in the probabilities of landing on the fourth position (1.75) and the fifth position (2.25) was marginally significant, $p = .061$. To summarize, a preference of landing on word center was found for 2-character words. The preferred landing position on 3-character words was slightly to the left of the word center. This pattern of results was similar to that found in alphabetic scripts and a recent study of Chinese reading (Yan, Kliegl, Richter, Nuthmann, & Shu, 2010).

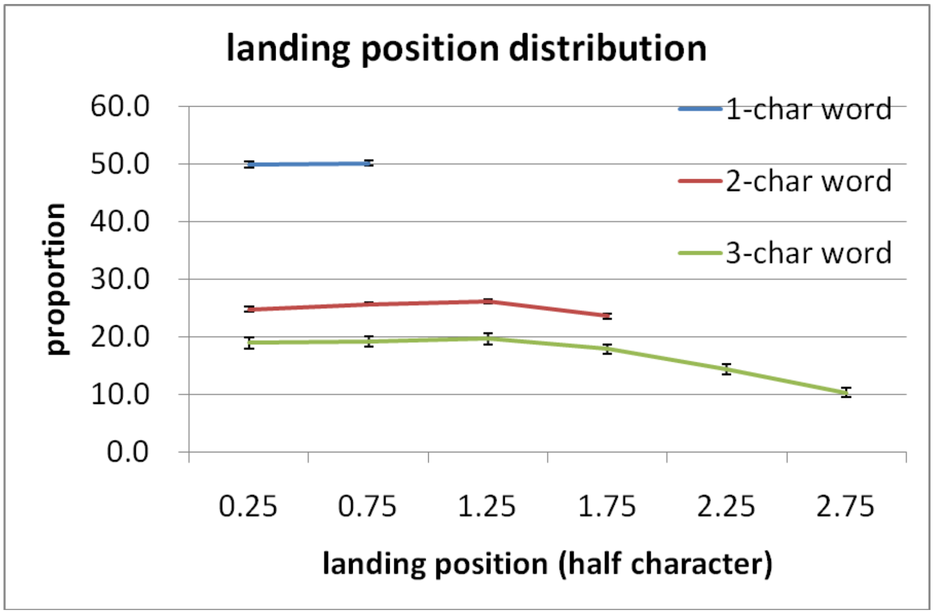

Figure 3. Initial landing positions on 1-, 2- and 3-character words.

Although the PVL and OVP were found to coincide with each other in reading western languages, they are different concepts. The preferred viewing location is not necessary the optimal viewing position for word recognition. The (preferred) initial landing position is determined by linguistic processing and oculomotor factors as well. In this experiment, the OVP was inferred from the curve of refixation probability as a function of initial landing position. If participants initially fixated at the optimal viewing position for word recognition, the probability of refixating the word should be reduced because recognizing and processing the word was the easiest at this position. The refixation probability is shown in Figure 4. The refixation probability on 1-character word was equally low (1.4 and 1.6%) regardless of the initial landing position, $F < 1$. For 2-character words, refixation probability was lower when the initial landing position was close to the word center than when it was close to word boundaries, $F(3,141) = 19.52$, $p < .001$. Both the linear and quadratic trends were significant, $F(1,47) = 5.73$, $p < .05$ and $F(1,47) = 57.99$, $p < .001$, respectively. Post-hoc pair comparisons showed that refixation probability at the third position (1.25; 4.7%) was significantly lower than those at the first position (0.25; 9.9%), $p < .001$ and the fourth position (1.75; 7.5%), $p < .01$. Refixation probability at the second position (0.75; 5.2%) was also lower than the first and fourth positions, $p < .001$ and $p = .065$, respectively. The difference between the second and the third positions as well as the difference between the first and the fourth positions were not significant, both *p*s > .10. For 3-character words, there were two participants who did not fixate at the last position, thus their data were excluded from analysis. Refixation probability was lower when the initial landing position was around word ending, $F(5,225) = 12.33$, $p < .001$. Both the linear and quadratic trends were significant, $F(1,45) = 41.47$, $p < .001$ and $F(1,45) = 6.71$, $p < .05$, respectively. Post-hoc pair comparisons showed that refixation probability was higher at the first position (27.6%) than those at the third to sixth positions (13.8, 11.8, 7.9, and 10.3 %), all *p*s < .01. Refixation probability was also higher at the second position (21.0%) than those at the fourth to sixth positions, *p* = .063, .005, and .060, respectively. The differences in refixation probabilities at the third to sixth positions were not significant, all *p*s > .16. To summarize, for 2-character words, the probability of landing on word center was higher than on word boundaries and the refixation probability was lower when the initial landing position was around word center than word boundaries. This result might suggest that PVL and OVP overlap. However, it is easier to recognize a 3-character word while fixating word ending although the PVL was around word beginning. This is probably due to the fact that Chinese words are not explicitly delineated in sentences. It is not easy to segment a long word from the parafovea; hence, probability of initially fixating word beginning was higher than word ending. However, it is easier to recognize the long word if participants fixated on word ending. The discrepancy between PVL and OVP was interesting in the context of the Chinese writing system in which there is no physical cue for word boundaries. Whether or not Chinese readers are sensitive to the probability of a character being used as word beginning/ending was investigated in the following analysis.

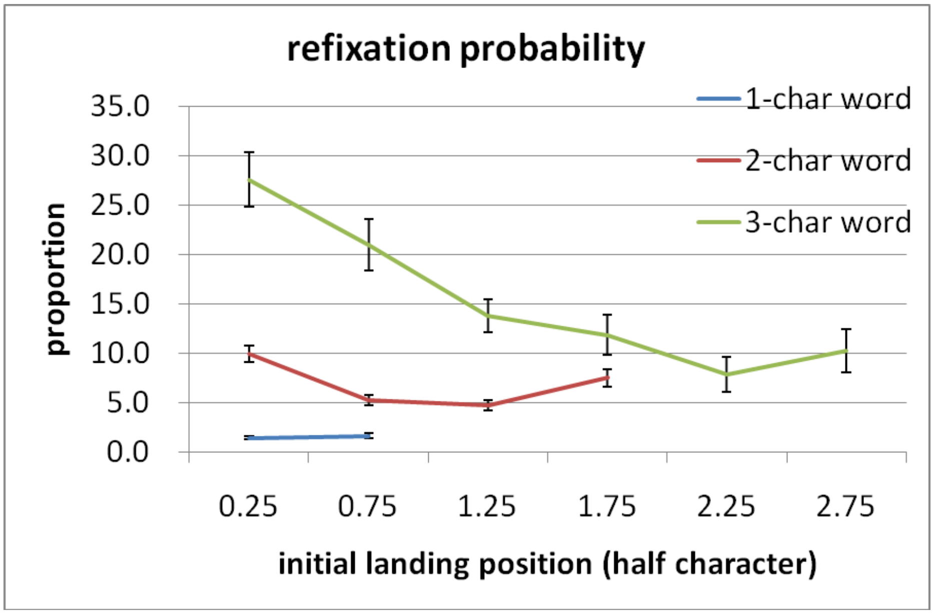

Figure 4. Refixation probability as a function of the initial landing position on 1-, 2- and 3-character words.

Gaze Durations and Statistical Cues for Word Boundaries. The analysis was restricted to 2-character words because their occurrence in the reading material in the corpus and in this experiment was higher than longer words. The probability of a character being used as word beginning/ending was calculated in three ways introduced in the materials section. The congruency of character-to-word assignment was a continuous variable. For the beginning character of a particular 2-character word, it is congruent if the probability of being word beginning is 100%. It is incongruent if the probability is 0%. On the other hand, for the ending character of a particular 2-character word, it is congruent if the probability of being word ending is 100%. Thus, two factors were considered in this analysis, namely, congruency of the first character (C1) and the second character (C2) of any 2-character words. Because congruency is a continuous variable, it is better to investigate its contribution with regression analysis rather than categorizing it into groups (e.g., high, median and low) with the ANOVA. Thus, the linear mixed effects modeling approach (LME; Baayen, 2008; Baayen, Davidson, & Bates, 2008) was used to include random effects from participants as well as auto-correlation within each individual. The LME approach does not require prior averaging across participants; instead, it works with fixation-based data set directly. Various factors can be added in the model as predictors for a particular dependent variable – gaze duration in this experiment. The statistical procedure was conducted by using the lmer program (lme4 package; Bates, Maechler, & Dai, 2008) in the R system (R Development Core Team, 2008). Both C1 and C2 congruency (the probability of being word beginning and ending, respectively) were centered at 0.5 (i.e., 50%). That is, the regression coefficient should be interpreted as the simple slope (of C1 congruency, for example) when the other factor (i.e., C2 congruency) was set to 0 (50%). The estimated effect size (*b*), standard error, and *t* value for each effect were reported. The *p* values were obtained through Markov Chain Monte Carlo (MCMC) sampling.

First, when the congruency was calculated with type frequencies of 2-character words, C2 congruency significantly reduced GD on the words ($b = -13.0$, $SE = 4.604$, $t = -2.82$, $p < .01$). Neither the effect of C1 congruency ($b = -3.6$, $SE = 5.059$, $t = -0.72$, $p > .47$) nor the interaction ($b = 17.5$, $SE = 20.253$, $t = 0.86$, $p > .38$) was significant. The higher the congruency of the ending character of 2-character words (i.e., the higher the probability of this character being used as word ending), the shorter the gaze duration was. This pattern did not vary significantly as C1 congruency varied along the continuum although it is almost negligible when C1 was 100% congruent (Figure 5-a).

Second, when the congruency was calculated with token frequencies of 2-character words, C2 congruency again significantly reduced GD on the words ($b = -26.9$, $SE = 4.697$, $t = -5.73$, $p < .001$). In addition, C1 congruency also significantly reduced GD on the words ($b = -16.1$, $SE = 4.481$, $t = -3.58$, $p < .001$). Furthermore, a significant interaction was also observed ($b = 58.2$, $SE = 16.150$, $t = 3.61$, $p < .001$). Gaze durations on words were reduced as C1 and C2 congruency increased. However, the slope of reduction in GD as the congruency of a character increased was modulated by the congruency of another character. For instance, as shown in Figure 5-b, the effect of C2 congruency was the highest when C1 was 100% incongruent and was almost negligible when C1 was 100% congruent. The same pattern held for C1 congruency.

Third, when the congruency was calculated with token frequencies of 2-character words divided by sum of token frequencies of all words regardless of word length, C2 congruency significantly reduced GD on the words ($b = -15.5$, $SE = 4.018$, $t = -3.87$, $p < .001$). However, neither the effect of C1 congruency ($b = -0.7$, $SE = 4.265$, $t = -0.17$, p

> .86) nor the interaction (*b* = 21.2, *SE* = 18.534, *t* = 1.14, *p* > .25) was significant. The pattern of result was shown in Figure 5-c.

To summarize, the effect of C2 congruency was reliable and robust among all three ways of calculating congruency. Furthermore, the effect was more profound when C1 was incongruent. A smaller and less reliable effect of C1 congruency was also observed. These results indicated that Chinese readers are sensitive to the probability of a character being used as word beginning/ending and word recognition time (in terms of GD) was reduced accordingly. Presumably because the left-side boundary of the fixated word has been determined, it is more important to find out word ending. Thus, the effect of C2 congruency was found to be larger than C1 congruency. Further studies with direct manipulation of C1 and C2 congruency are necessary to clarify the finding of this experiment.

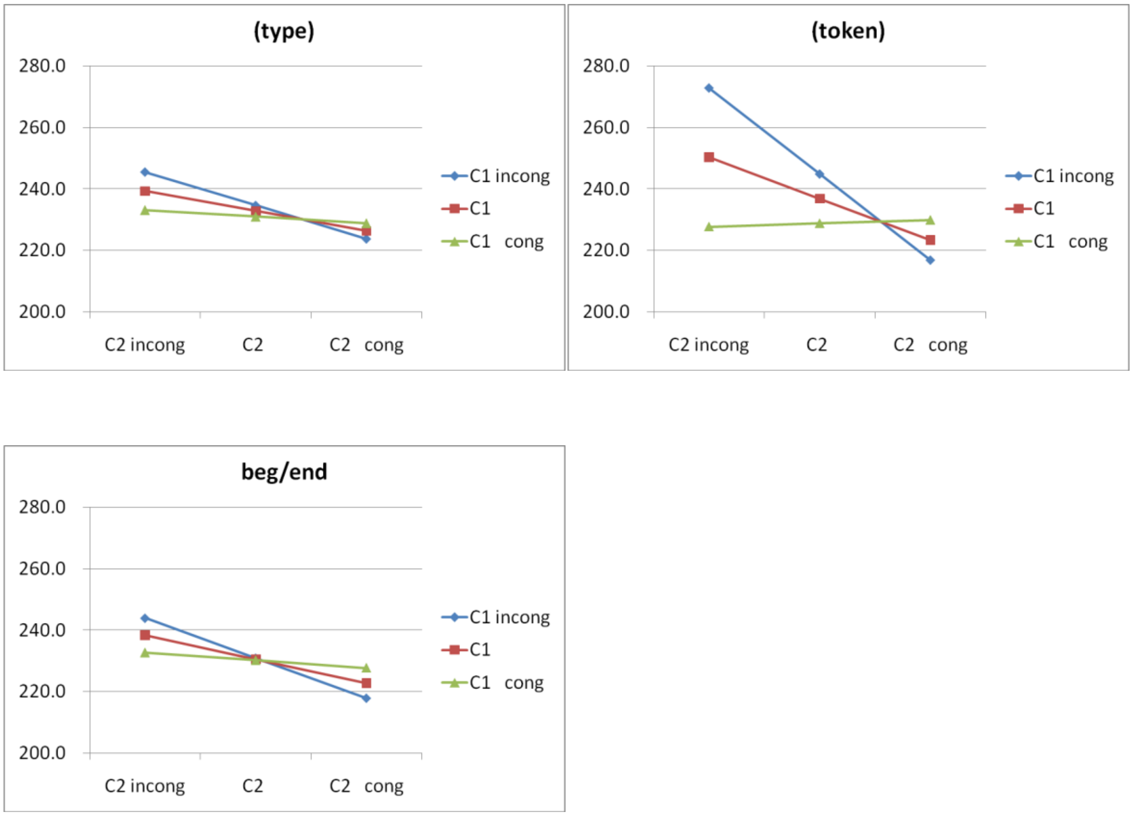

Figure 5. Gaze duration as a function of C2 congruency (C2 incong: 0% congruent; C2: 50% congruent; C2 cong: 100% congruent). The lines were plotted as C1 congruency

varied (C1 incong: 0% congruent; C1: 50% congruent; C1 cong: 100% congruent). The congruency was calculated (a) with type frequencies of 2-character words; (b) with token frequencies of 2-character words; (c) with token frequencies of 2-character words and were divided by sum of frequencies of all words of various lengths.

Year 3-1: OVP on Words (Neighborhood Size Effects)

The purpose of the experiments in Year 3 was to investigate the influence of sub-lexical information profile on word/character recognition. In two experiments, a two-character word or a single character was presented in isolation. Participants were instructed to decide whether the presented stimulus was a word/character or not. The fixation position of the stimulus was manipulated. While participants kept fixating the center of the screen, the stimulus was presented at one of five positions relative to the fixation point (Figures 6 and 8). In Experiment 1, number of two-character words that contain the first character of the target word was calculated as the index of neighborhood size 1 (NS1). NS2 was calculated in a similar way in which the second character was taken into consideration. The orthogonal manipulation of NS1 and NS2 (large and small) together with fixation position enabled us to examine the role that informativeness of sub-lexical units plays during word recognition. Similarly, in Experiment 2, number of semantic-phonetic compound characters that contain the semantic/phonetic radical of the target character was computed. The contribution of the informativeness of radicals to character recognition was then investigated.

In the classical paper, Coltheart, Davelaar, Jonasson, and Besner (1977) defined orthographic neighbors as words that share all but one letters while keeping word length and letter position constant. Investigating how similar words influence each other sheds light on the organization of the mental lexicon and the process of lexical access. Some researchers observed facilitative effects in which reaction time to target words with more neighbors was faster than those with less neighbors while others observed inhibitory effects (see Andrews, 1997, for a review). Grainger and Jacobs (1996) proposed that there were two mechanisms. First, the activation of neighbors enhanced global lexical activity which in turn facilitated positive response. Second, lexical inhibition between similar words (especially by higher frequency neighbors) impeded the activation of the target word. The seemly contradictory findings resulted from a combination of these two mechanisms which could be modulated by task-specific criteria (e.g., emphasis on accuracy or speed) and the frequency of neighbors.

A majority of Chinese words are composed of two characters (Academia Sinica Taiwan, 1998). A character can be combined with different characters to form different words. In Chinese, the neighborhood size of two-character words can be calculated separately for each constituent character (Huang, Lee, Tsai, Lee, Hung, & Tzeng, 2006). Neighborhood size 1 (NS1) refers to the number of two-character words that share the beginning character while neighborhood size 2 (NS2) refers to the number of words that share the ending character.

Huang, et al. (2006) found a facilitative neighborhood size effect for high frequency words and an inhibitory effect for low frequency words. In a supplementary regression analysis, they found that word frequency, NS1, and the number of higher frequency neighbors of the first character (HFN1) contributed to the variance in reaction time, while NS2 and HFN2 did not. NS1 had a facilitative effect and HFN1 had an inhibitory effect. This provided an explanation for the inhibitory effect for low frequency words since they have more HFNs than high frequency words. In addition, the result of the regression analysis implies that the first character plays a dominant role in word recognition. In their second experiment, both NS1 and HFN1 were manipulated. The results showed that a facilitative NS1 effect was evident only when the target word had no HFN. Also, when NS1 was large, the inhibitory effect of having HFNs was evident.

In this experiment, NS1 and NS2 of two-character words were manipulated orthogonally in addition to the manipulation of fixation positions. If these factors play a role in word recognition, they may influence the OVP. Furthermore, as observed in the study of Huang et al. (2006), the first character may play a dominant role in word recognition.

Method

Participants. Twenty college and graduate students at National Chengchi

University were paid to participate in this experiment. All of them are native speakers of Chinese with normal or corrected-to-normal vision.

Design and Materials. Two hundred and forty two-character strings were chosen as the stimuli. Half of them were real words and the other half were pseudowords. There were three independent variables. First, as is shown in Figure 6, there were five fixation positions. The fixation point was set at the center of the screen, and the two-character string was presented at different position relative to the fixation point according to the condition. The second and third independent variables were neighborhood sizes concerning the first and second constituent characters, respectively. Number of words that share the first character with the target word was calculated as the index NS1 (neighborhood size 1). Similarly, number of words that share the second character was calculated as the index NS2. The sizes of NS1 and NS2 were manipulated orthogonally. In half of the stimuli, NS1 was larger than 40; while in the other half, it was smaller than or equal to 10. The cutoff points for NS2 were the same. The two by two orthogonal manipulation resulted in 4 conditions. As shown in Table 2, there was no difference in word frequency among 4 conditions ($F(3,116) = 1.03$, $p > .38$). The difference between NS1-Large and NS1-Small was significant for real words and pseudowords (*p*s < .001). Similarly, the difference between NS2-Large and NS2-Small was also significant (*p*s < .001).

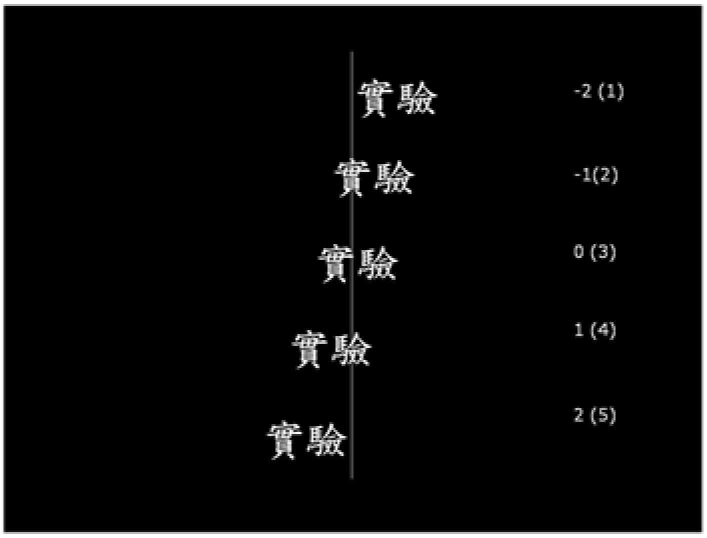

Figure 6. Illustration of five fixation positions in Experiment 3-1.

Table 2. Mean linguistic properties of the stimuli in each condition.

NS1	Large	Large	Small	Small
NS2	Large	Small	Large	Small
		Real Word		
Word frequency (per million)	2.9	2.4	2.6	2.4
NS1	66.2	71.6	6.5	6.9
NS2	75.7	5.8	70.6	6.3
		Pseudoword		
NS1	62.2	58.8	6.7	6.7
NS2	62.3	6.4	61.8	6.0

Apparatus. Similar to that in Year 1. The characters were shown in black on a light gray background. The characters, which extended 40 × 40 pixels, were shown at one of the five fixation positions around the center of the screen according to condition. The viewing distance was 74 cm, at which each character subtended 1.02°.

Procedure. Participants were instructed to decide whether the stimulus was a legal Chinese word or not by pressing buttons on a response box. After a 9-point calibration and verification for calibration accuracy, there were 10 practice trials.

At the beginning of each trial, a cross was presented at the center of the screen as the fixation point. If the participants' eyes remained stable for 60 ms within ±5 pixels around the center of the cross, the stimulus was presented. Otherwise, the position of the tracked eye was monitored until it remained stable and met the criterion. If the criterion was not met after 3s, the calibration procedure was repeated. The stimulus was presented for 100 ms. As shown in Figure 6, the stimulus was presented at one of the five positions relative to the fixation point according to the condition. The participants were instructed to respond with both hands as quickly and accurately as possible. The next trial began when the participants pressed a button or after 2 s. There were totally 240 experimental trials divided into 3 blocks. Two filler trials were added to the beginning of each block. Participants could take a break after each block. The experiment lasted about 30-40 minutes.

Results

Response time and accuracy were recorded. Only real words and correct responses were analyzed. For each participant, the mean and standard deviation in each condition was calculated. Response time within the mean ±2.5 SD was kept for analysis. The means and standard errors of response time on words in each condition are shown in Table 3.

Table 3. Means and standard errors of reaction time in each condition.

position	1	2	3	4	5	Overall
	凝視 |	凝視 |	凝視 |	凝視 |	凝視 |	
N1L_N2L	658.5 (19.1)	652.6 (23.5)	631.7 (15.8)	666.0 (19.5)	677.6 (19.0)	657.3 (16.2)
N1L_N2S	672.4 (16.6)	658.3 (18.5)	651.2 (18.0)	670.5 (18.1)	671.3 (15.7)	664.7 (14.7)
N1S_N2L	664.7 (20.6)	651.8 (18.2)	654.8 (14.9)	662.1 (13.9)	685.7 (16.1)	663.8 (13.9)
N1S_N2S	636.7 (18.3)	643.9 (17.6)	638.4 (15.8)	639.0 (16.4)	669.1 (15.8)	645.4 (14.4)
N1L	665.4 (15.4)	655.5 (19.7)	641.4 (15.6)	668.3 (17.0)	674.5 (16.1)	661.0 (15.3)
N1S	650.7 (18.5)	647.9 (16.7)	646.6 (13.6)	650.5 (13.7)	677.4 (14.3)	654.6 (13.9)
N2L	661.6 (18.2)	652.2 (19.9)	643.3 (13.7)	664.0 (15.2)	681.7 (16.7)	660.6 (14.9)
N2S	654.5 (16.2)	651.1 (17.0)	644.8 (14.7)	654.8 (16.0)	670.2 (13.7)	655.1 (14.2)
overall	658.1 (16.0)	651.7 (17.9)	644.0 (13.3)	659.4 (14.6)	675.9 (14.5)	

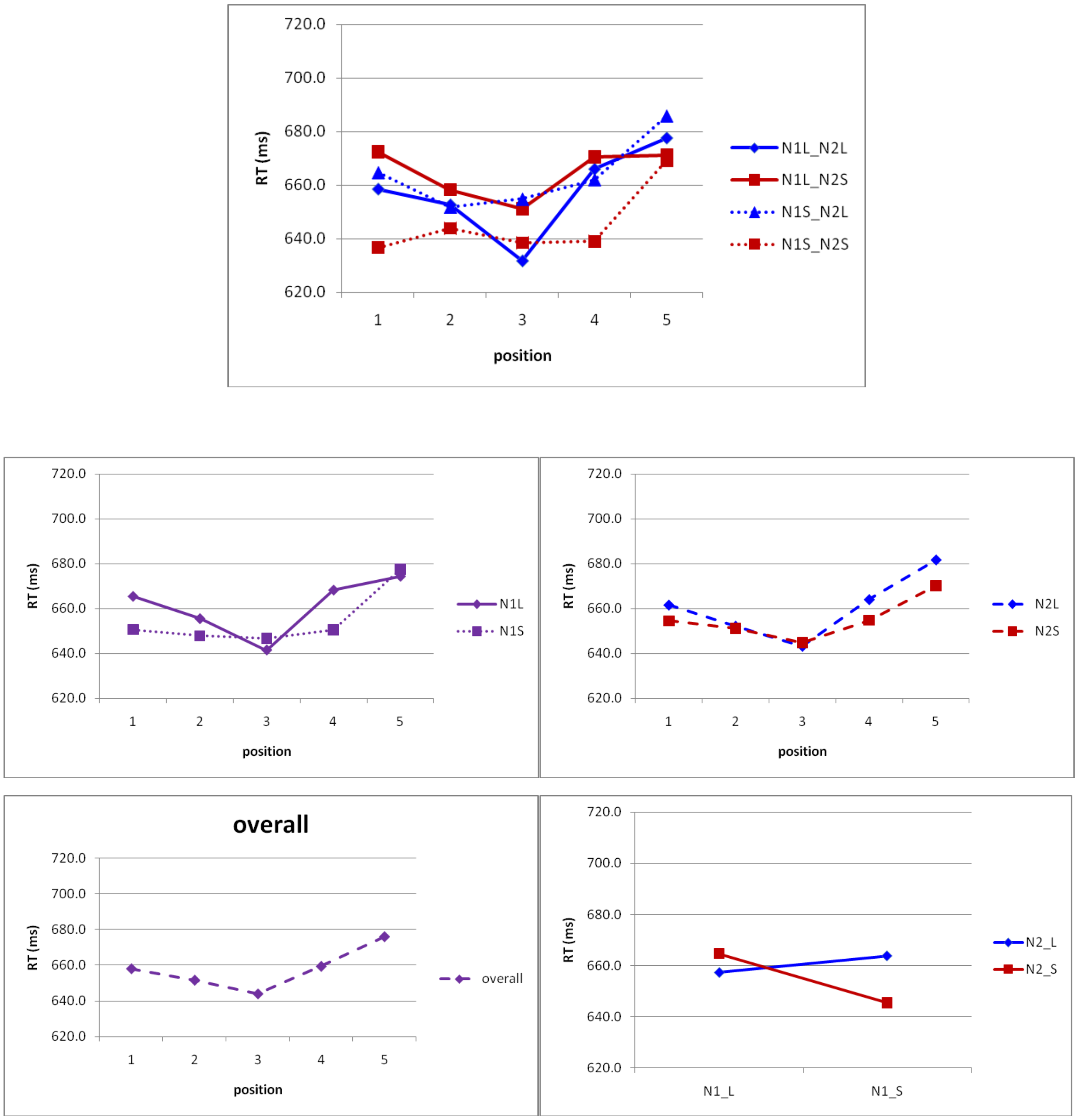

Figure 7. Mean reaction time in (a) all 2 x 2 x 5 conditions; (b) comparison of large and small NS1 at 5 fixation positions; (c) comparison of large and small NS2 at 5 fixation positions; (d) overall effect of fixation positions; (e) effects of NS1 and NS2.

Fixation Position. The effect of fixation position on reaction time was significant [$F_1(4,76) = 4.06$, $MS_e = 2755$, $p < .01$; $F_2(4, 464) = 3.74$, $MS_e = 1784$, $p < .01$]. When the whole word was presented to the left of the fixation point (position 5), reaction time was significantly longer than that when the word was presented at the center of the screen (position 3), *p*s < .01. All other pairwise comparisons were not significant, *p*s > .10.

Neighborhood Size. When the manipulation of neighborhood size was considered as one factor with 4 conditions, there was a significant neighborhood size effect [$F_1(3,57) = 4.98$, $MS_e = 1592$, $p < .01$; $F_2(3, 116) < 1$, $MS_e = 14820$]. The reaction time in the N1S_N2S condition was the shortest, and it was significantly shorter than that in the N1L_N2S and N1S_N2L conditions by participants, *p*s < .05.

Interaction Between Neighborhood Size (4) and Fixation Position (5). The interaction between neighborhood size and fixation position was not significant, *F*s < 1. However, the effect of fixation positions seems to be different among neighborhood size conditions. In the N1S_N2S condition, there was virtually no difference among positions 1~4. In the other conditions, numerically, reaction time at position 2 was shorter than that at position 4; similarly, reaction time at position 1 was shorter than that at position 5. The pattern of results suggests that the optimal viewing position for two-character word recognition is slightly to the left of the word center.

Neighborhood Sizes 1 and 2. When the manipulation of neighborhood size was considered as two orthogonal factors, there was a significant interaction between NS1 and NS2 [$F_1(1,19) = 13.13$, $MS_e = 1272$, $p < .01$; $F_2(1, 116) = 1.47$, $MS_e = 14820$, $p > .22$]. In the participant analysis, the effect of NS1 was significant only when NS2 was small ($p < .01$). Similarly, the effect of NS2 was significant only when NS1 was small ($p < .01$). This pattern resulted from the observation that reaction time in the N1S_N2S condition was the shortest among all conditions. There were no significant main effects of NS1 and NS2, *F*s < 2.10, *p*s > .16.

Simple Interaction of Neighborhood Sizes 1 and 2 (2 × 2) with Fixation Position (5). There was no significant interaction with fixation position. However, the NS1 × NS2 interaction was evident at positions 1 and 4. Concerning the NS1 effect when NS2 was small, the 35 ms and 32 ms difference at positions 1 and 4 were significant, *p*s < .05. Concerning the NS2 effect when NS1 was small, the 28 ms difference at position 1 was significant, $p < .05$ while the 23 ms difference at position 4 was not, $p = .102$.

Simple Main Effect of Neighborhood Size 1 or 2 (2) with Fixation Position (5). The effect size of NS1 at positions 1 to 5 was 15, 8, -5, 18, and -3 ms, respectively, *p*s > .08. The effect size of NS2 at positions 1 to 5 was 7, 1, -2, 9, 11 ms, respectively, *p*s > .23.

Discussion

The optimal viewing position on two-character words for word recognition was slightly to the left of the word center. Reaction time was the longest when the whole word was presented in the left visual field (position 5). Numerically, reaction time at positions 1 and 2 was shorter than positions 5 and 4, respectively.

There was a significant interaction between NS1 and NS2. Reaction time to words with small NS1 and small NS2 was the shortest. When NS2 was small, reaction time to words with large NS1 was longer than those with small NS1. When NS2 was large, the effect of NS1 was opposite but not significant. The pattern of the simple effects of NS2 was the same. The observation that NS1 and NS2 had inhibitory effects is consistent with that in the study of Huang et al. (2006). In the present experiment, low frequency words were chosen as the stimuli. In addition, almost all target words had higher frequency neighbors. The larger the neighborhood size was, the more HFNs the target word had. Thus, we observed an inhibitory effect. Alternatively, the inhibitory effect can be interpreted as a constraining effect in which words are easy to recognize if there are only a few orthographic neighbors.

Considering the interaction between neighborhood sizes and fixation position, when NS1 was small, there was virtually no effect of fixation position except when the whole word was presented in the left visual field (position 5). The simple interaction between NS1 and fixation position did not change according to NS2. When NS2 was large, the curve shifted upward, suggesting that words with large NS2 were harder to process than words with small NS2. However, when NS1 was large, the OVP was to the left of word center. This pattern was more evident when NS2 was also large.

Overall, the result suggests that NS1 is dominant for word recognition. When NS1 was small, reaction time was short regardless of fixation position. This suggests that when a word is easy to recognize, the fixation position does not have an effect. If NS2 was also small, the reaction time was the shortest. This suggests that when both characters are constraining, word recognition benefit the most. When NS1 was large and the word was hard to recognize, fixation position had its effect. Although the observation that OVP located to the left of word center suggests that the first character is important for word recognition, it is puzzling because when NS1 was large, the first character did not provide helpful information, the OVP should locate at the second character. It is also puzzling when NS1 was large, small NS2 did not seem to be constraining. Instead, large NS2 seemed to facilitate word recognition and the OVP curve was more evident in the N1L_N2L condition. The observation that the simple interaction between NS1 and NS2 was evident at positions 1 and 4 may be a complicated by-product.

Year 3-2: OVP on Characters (Radical Combinability Effects)

Only a few Chinese characters are simple characters, for example, 山 ‘mountain’ and 上 ‘up’, that cannot be decomposed into smaller parts. Among characters that consist of smaller parts, a majority of them are semantic-phonetic compounds, e.g., 眼 ‘eye’. These characters have a semantic radical that signals the semantic category of the character and a phonetic radical that suggests the pronunciation of the whole character. Most semantic-phonetic compounds have the SP structure in which the semantic radical is located at the left-hand side and the phonetic radical is located at the right-hand side (Hsiao & Shillcock, 2006). Similar to multi-character words, whose constituent characters can combine with other characters to form different words, both phonetic and semantic radicals can combine with different radicals to form different characters. The number of characters that share the same semantic radical is referred to as semantic combinability while that share the same phonetic radical is referred to as phonetic combinability.

Hsu, Tsai, Lee, and Tzeng (2009) investigated the effect of phonetic combinability with a homophone judgment task. During the experiment, electrophysiological responses were recorded. In addition, whether or not the group of characters that share the same phonetic radical with the target character has consistent pronunciation was manipulated. They found a larger N170 component for high combinability than low combinability characters (for highly-consistent characters only) suggesting that a large group of orthographic neighbors elicited greater perceptual-level activation during the initial processing (less than 200 ms). High combinability characters also reduced the P200 component indicating a facilitative effect at the orthographic level. Then, high combinability characters enhanced the N400 component implying a large semantic competition among candidate characters. Thus, high combinability initially increased activation at the perceptual and orthographic levels and facilitated character processing, but later interrupted the process because of competition among characters that share the same radical.

Hsiao, Shillcock, and Lavidor (2006) proposed that small semantic combinability is more informative than large one because only a few characters share the same semantic radical. Also, when the character has a large combinability semantic radical, its phonetic radical becomes more informative than the semantic radical. In their experiment, the target character was presented at the center of the fixation point, so that the semantic radical was presented in the left visual field (LVF) and was projected to the right hemisphere (RH) initially. In contrast, the phonetic radical was presented in the right visual field (RVF) and projected to the left hemisphere (LH). During the experiment, they applied transcranial magnetic stimulation (TMS) over the RH or LH. The reaction to character with large semantic combinability was significantly different when the TMS was applied to the LH than when it was applied to the RH or the control condition. This is because when semantic combinability was large, the phonetic radical played a more important role. Thus, when the TMS was applied to the LH where the phonetic radical was initially projected, it interfered with character recognition. Note, however, the effect of semantic combinability (facilitative / inhibitory) depends on task demand and the types of filler stimuli. Cheng (2006) showed that when pseudo-characters (combining two legal radicals) were used, an inhibitory effect was observed because participants had to examine whether the stimulus was a legal combination or not. When non-characters (deleting or adding strokes) were used, a facilitative effect was observed because participants can make decision simply based on familiarity.

In the second experiment of Year 3, we aimed to investigate the effects of radical combinability on character recognition by simultaneously manipulating both the semantic and phonetic radicals. In addition, fixation position was manipulated to examine whether one radical play a dominant role or both radicals are important.

Method

Participants. Twenty-five college and graduate students at National Chengchi University were paid to participate in this experiment. All of them are native speakers of Chinese with normal or corrected-to-normal vision.

Materials. One hundred and twenty real characters, sixty pseudo-characters, and sixty non-characters were chosen as the stimuli. Real characters were chosen from the Academia Sinica balanced corpus (1998). The mean character frequency was 5.0 per million (range = 0.34~85.4). The mean number of strokes was 13.4 (range = 7~20). All real characters were semantic-phonetic compounds with their semantic and phonetic radicals located at the left and right hand side, respectively. The combinability of a semantic radical was the number of characters in which this radical serves as the semantic radical. Similarly, the combinability of phonetic radical was the number of characters in which this radical serves as the phonetic radical. Both measures are positively skewed in the corpus. The combinability of semantic radical ranges from 1 (such as 鼻 in 鼾) to 226 (氵 in 汗), with the median of 74. On the other hand, the combinability of phonetic radical ranges from 1 (such as 丞 in 拯) to 20 (such as 非 in 排), with the median of 6. The median of the combinability of semantic and phonetic radicals of the real characters used in this experiment were 71 and 6 (range = 4~226, 3~20), respectively. Pseudo-characters were created by combining a semantic and a phonetic radical but the combination does not exist as a real Chinese character. The mean number of strokes of the pseudo-characters was 13.0 (range = 7~20). The median of the combinability of semantic and phonetic radicals of the pseudo-characters used in this experiment were 42 and 5 (range = 3~226, 3~16), respectively. Non-characters were created by adding/deleting one stroke from real characters. The mean number of strokes of the non-characters was 12.2 (range = 5~24).

Apparatus. Similar to that in Experiment 3-1, except that each character extended 48 × 48 pixels and subtended 1.22°.

Procedure. Similar to that in Experiment 3-1, the stimulus was presented at one of five positions relative to the fixation point according to the condition as shown in Figure 8. Participants were instructed to decide whether the stimulus was a legal Chinese character or not by pressing buttons on a response box. Other procedure was the same as that in Experiment 3-1.

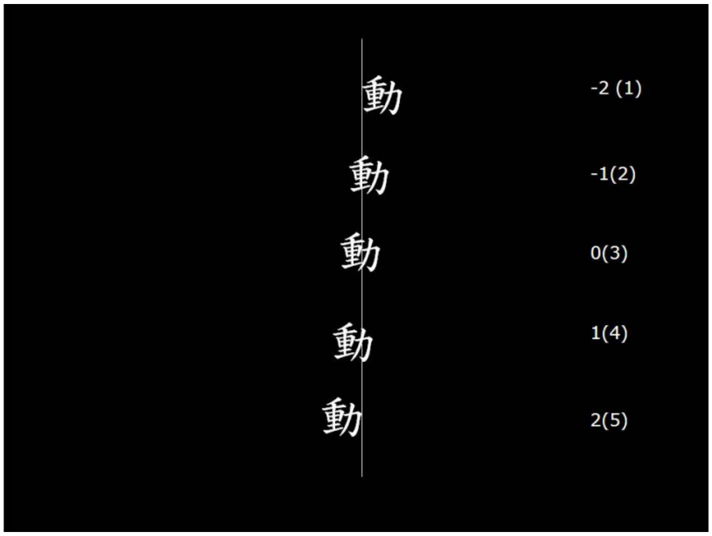

Figure 8. Illustration of five fixation positions in Experiment 3-2.

Results

Response time and accuracy were recorded. Only real characters and correct responses were analyzed. For each participant, the mean and standard deviation in each condition was calculated. Response time within the mean ±2.5 SD was kept for analysis. The data set was median split by semantic and phonetic combinability. Characters with semantic combinability higher than 71 were categorized as the SL group (large semantic combinability), while those lower than 71 were categorized as the SS group (small semantic combinability). Half of the characters fell in each category. Similarly, characters with phonetic combinability higher than or equal to 6 were categorized as the PL group (large phonetic combinability), while those lower than 6 were categorized as the PS group (small phonetic combinability). Sixty-four characters fell in the former group and fifty-six characters fell in the latter group. The categorization results in 4 orthogonal groups. Number of characters in the SL_PL, SL_PS, SS_PL, and SS_PS groups were 25, 35, 31, and 29, respectively. The means and standard errors of response time on real characters in each condition are shown in Table 4.

Table 4. Means and standard errors of reaction time in each condition.

position	1	2	3	4	5	Overall
	眼 |	眼 |	眼 |	眼 |	眼 |	
SL_PL	674.1 (17.8)	668.1 (19.1)	695.1 (17.8)	699.5 (21.5)	684.4 (17.5)	684.2 (15.9)
SL_PS	699.0 (16.2)	701.3 (18.7)	686.7 (17.8)	700.6 (17.5)	696.9 (17.9)	696.9 (14.9)
SS_PL	669.8 (15.7)	684.2 (17.8)	678.6 (13.5)	674.5 (15.5)	682.3 (15.6)	677.9 (13.8)
SS_PS	709.0 (21.8)	682.7 (16.8)	668.0 (14.1)	673.8 (18.8)	662.1 (15.8)	679.1 (14.6)
SL	686.5 (14.9)	684.7 (17.0)	690.9 (17.0)	700.0 (18.0)	690.6 (17.0)	690.6 (15.1)
SS	689.4 (17.9)	683.4 (16.4)	673.3 (12.6)	674.2 (15.5)	672.2 (14.5)	678.5 (13.9)
PL	671.9 (15.2)	676.1 (17.3)	686.9 (14.6)	687.0 (16.7)	683.4 (15.5)	681.1 (14.6)
PS	704.0 (17.7)	692.0 (16.5)	677.4 (14.7)	687.2 (16.3)	679.5 (15.8)	688.0 (14.5)
overall	687.9 (15.6)	684.0 (16.2)	682.1 (14.0)	687.1 (15.4)	681.4 (15.2)	

Fixation Position. These was no effect of fixation position on reaction time [$F_1(4,96) <1$, $MS_e = 3582$; $F_2(4, 464) < 1$, $MS_e = 3881$].

Semantic and Phonetic Combinability. Reaction time to characters with large semantic combinability was significantly longer than that with small semantic combinability [$F_1(1,24) = 8.14$, $MS_e = 2234$, $p < .01$; $F_2(1, 116) = 3.11$, $MS_e = 5596$, $p = .081$]. Reaction time to characters with large phonetic combinability was slightly shorter than that with small phonetic combinability [$F_1(1,24) = 2.42$, $MS_e = 2497$, $p > .13$; $F_2(1, 116) < 1$, $MS_e = 5596$].

The interaction between semantic and phonetic combinability was not statistical significant [$F_1(1,24) = 2.12$, $MS_e = 1933$, $p > .15$; $F_2(1, 116) < 1$, $MS_e = 5596$]. But the effect of semantic combinability was evident when the phonetic combinability was small (18 ms, $p < .01$, by participants; 14 ms, $p = .098$, by items) while the effect was negligible when the phonetic combinability was large (*p*s > .32). The effect of phonetic combinability was evident when the semantic combinability was large (-13 ms, $p = .051$, by participants; -3 ms, $p > .70$, by items) while the effect was negligible when the semantic combinability was small (*p*s > .64).

The Interactions Between Fixation Position and Each Radical Combinability. The interaction between fixation position and semantic combinability was significant by items [$F_1(4,96) = 1.38$, $MS_e = 2734$, $p > .13$; $F_2(4, 464) = 5.07$, $MS_e = 3881$, $p < .01$]. The effect of semantic combinability was getting evident as the fixation position shifted rightwards. The effect sizes were -3, 1, 18, 26, and 18 ms, *p*s = .78, .89, .098, .063, and .035, respectively.

The interaction between fixation position and phonetic combinability was significant [$F_1(4,96) = 3.10$, $MS_e = 2301$, $p < .05$; $F_2(4, 464) = 1.70$, $MS_e = 3881$, $p > .14$]. The effect of phonetic combinability was getting evident as the fixation position shifted leftwards. The effect sizes were -32, -16, 9, 0, and 4 ms, *p*s = .006, .12, .25, .98, and .59, respectively.

The three way interaction was significant by items [$F_1(4,96) = 1.34$, $MS_e = 2134$, $p > .26$; $F_2(4, 464) = 2.70$, $MS_e = 3881$, $p < .05$]. The effect of semantic combinability was significant with small phonetic combinability at position 5 (the rightmost position), $p < .01$. The effect size of phonetic combinability was -39 and -25 ms with small and large semantic combinability at position 1 (the leftmost position), $p < .01$ and $p > .14$, respectively. The effect size of phonetic combinability was -33 ms with large semantic combinability at position 2, $p = .055$.

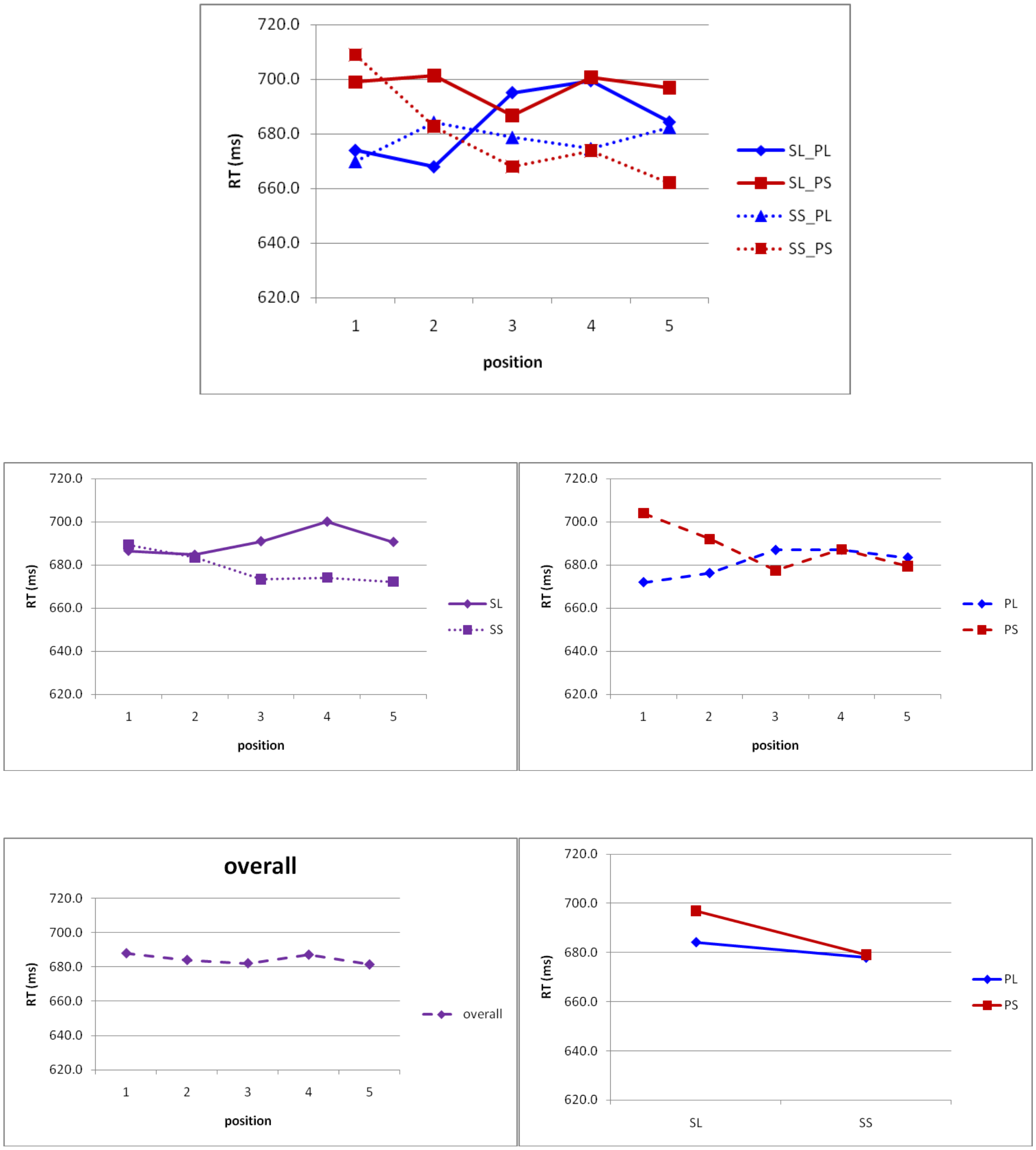

Figure 9. Mean reaction time in (a) all 2 x 2 x 5 conditions; (b) comparison of large and small semantic combinability at 5 fixation positions; (c) comparison of large and small phonetic combinability at 5 fixation positions; (d) overall effect of fixation positions; (e) effects of semantic and phonetic combinability.

Discussion

Overall, the effect of fixation position was not significant. However, the effect of radical combinability depends on fixation position. The effects of radical combinability will be discussed first and then their interaction with fixation position will be discussed.

Response time to characters with large semantic combinability was longer than those with small semantic combinability. This result suggests that when a large group of characters are associated with one semantic radical, it is hard to recognize individual character due to competition among all candidates. This is consistent with the findings of Hsiao et al. (2006).

In contrast, response time to characters with large phonetic combinability was shorter than those with small phonetic combinability. This result suggests that when a character shares the phonetic radical with a large group of characters, the activation of those characters facilitates the recognition of the presented character, which is consistent with the findings of Hsu et al. (2009).

The reason that semantic and phonetic combinability had opposite effects might be because the range of semantic combinability (1~226) was much larger than that of phonetic combinability (1~20). It is also possible that semantic and phonetic radicals serve different functions during character recognition. Phonetic radicals provide a repertoire of possible pronunciation of the whole characters. When more characters share the same phonetic radical with the target character, its lexical activation is stronger. On the other hand, semantic radical loosely indicate the semantic category of the target character. When more characters share the same semantic radical with the target character, it becomes vaguer to determine the meaning of the character. Thus, in general, reaction time to characters with large semantic combinability and small phonetic combinability was the longest. In addition, the effect of semantic combinability was evident when the phonetic combinability was small. Characters with small phonetic combinability were harder to recognize than those with large combinability. Under this situation, semantic combinability could have its effect. Characters with large phonetic combinability were easy to recognize, thus, the effect of semantic combinability was almost negligible. With similar rationale, the effect of phonetic combinability was evident when semantic combinability was large.

Concerning the interaction with fixation position, the effect of semantic combinability was getting evident when the fixation position was close to the phonetic radical. Similar pattern was observed for the effect of phonetic combinability. The interaction between both radical combinability and the interaction with fixation position suggest that processing of both radicals is equally important. When one radical is hard to process, the other radical exerts its effect. Also, when one radical is fixated, the other radical is taken into consideration.

General Discussion

In Years 1 and 2, the OVP curve was observed with lexical decision task (during which a word was presented in isolation) and normal text reading task. In Year 1, the stimuli were middle to low frequency words whose NS1 and NS2 were less than 30 with means 12.3 and 12.0, respectively. We observed an OVP slightly to the right of the center of two-character words. The observation of rightward asymmetric OVP curve was inconsistent with findings in other languages. However, the OVP near the second-character of word-ending may result from the special property of Chinese text which has no space between words to indicate word boundary. Chinese readers may have learned that word-ending provides the disambiguating information and they read faster at the second-character position even in the isolated presentation task.

In Year 2, we analyzed OVP in continuous text reading. For two-character words, the probability of fixating word center was higher than that of word boundaries (preferred viewing location, PVL) and the probability of refixating the target word was lower when readers initially landed at word center (which implies the OVP). For three-character words, the PVL was slightly to the left of word center, while the OVP was near the word ending. Presumably because there was no visual cue for word boundaries, readers tended to fixate at word beginning; but for a long word, it was easier to determine word boundary when word ending was fixated. In a linear mixed-effects analysis (Baayen, et al., 2008), we found that gaze durations on words were shorter when the second character was more likely to be used as word ending. Similarly, GDs were shorter when the first character was more likely to be used as word beginning (but this effect was less robust). Also, the effect was more evident when the other character was less likely to be used at its current position. This finding suggests that Chinese readers are sensitive to statistical information such as the probability of within-word character position for word recognition during text reading. Although the second character seemed to produce a reliable effect, it was modulated by the congruency of the first character. This suggests that both characters have their effects during text reading.

In Year 3, we directly investigated how the information profile of sub-lexical units influences lexical processing. In Experiment 3-1, effects of neighborhood sizes of both constituent characters on recognizing two-character words were examined. We found that the first character played a dominant role. When NS1 was small, it was easy to recognize the target word, so there was no effect of fixation position. When NS1 was large, an OVP to the left of word center was found. The findings suggest that the OVP is affected by lexical constraint or information profile of words which play a role in the process of word recognition.

A different picture was observed for character recognition in Experiment 3-2. Semantic combinability exerted an inhibitory effect while phonetic combinability exerted a facilitative effect. In addition, effect of one radical combinability was more evident when the other radical was less informative and when the other radical was fixated. These results suggest both radicals play important roles during character recognition. Unlike constituent characters in multi-character words, the function and the position of a radical in characters are highly related. Specifically, a majority of semantic-phonetic compound characters have their semantic radical at the left hand side and their phonetic radical at the right hand side. The close relationship between radical position and function may lead to the observation that both semantic and phonetic radicals are important for character recognition although they play different roles.

Taken together, whether one sub-lexical unit plays a dominant role or both units are equally important depends on the relationship between the function and position of the sub-lexical unit as well as on the task they involve in. In this project, the effects of the information profile of the sub-lexical units have been repeatedly observed under different conditions. Using statistical information to decode the presented stimuli seems to be an implicit but common strategy during reading. Manipulating fixation position together with the informativeness of the sub-lexical units is a good technique to study this cognitive operation. In addition, the characteristics of Chinese writing system also provide a unique platform for this issue.

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國科會補助專題研究計畫項下赴國外(或大陸地區)出差或研習心得報告

日期：99年8月10日

計畫編號	NSC 96-2413-H-004-018-MY3		
計畫名稱	中文詞彙辨識的凝視位置效果之決定因素（第 3 年）		
出國人員姓名	蔡介立	服務機構及職稱	國立政治大學心理系助理教授
出國時間	99年7月20日至 99年8月6日	出國地點	美國伊利諾大學香檳校區

本次於2010年7月20日至8月6日赴美國伊利諾大學香檳分校(University of Illinois at Urbana-Champaign) 心理系進行國際學術交流以及研究合作討論事宜。本次主要的參訪合作對象為UIUC心理系系主任Susan Garnsey教授，地點在UIUC校區內的Beckman Institute實驗室。Beckman Institute為私人資助設立於UIUC的研究機構，它的特色為將UIUC理工、生化、資訊、及認知心理領域的研究者放在一起，進行許多跨領域的議題討論與實質的研究合作，因此認知神經科學取向的研究，為此機構的主要研究特色之一。Susan Garnsey教授的實驗室即在Beckman Institute內，其研究專長主要是利用ERP和眼動儀兩項研究工具，來探討心理語言學的諸多議題，特別是在句法的層次上，Garnsey教授曾出版數篇以眼動探討句法處理歷程的文章，其指導的一位學生，即用傳統行為的逐詞按鍵的方式，來探討中文關係子句的處理。本次除了與Garnsey交流目前研究計畫的內容之外，也特別針對目前我們所做的中文關係子句研究，進行深入的討論。

在Beckman Institute的期間，除了參與實驗室的會議，介紹目前在台灣進行的各個眼動研究，也聆聽Garnsey及其實驗室的學生們報告正在進行的實驗，此外，

也有臨時工作的辦公室，和那邊的學生有更多互動的機會。討論的議題中，有關詞彙鄰項個數的中文閱讀研究受到最多的迴響與討論,由於中文詞的組成多為雙字詞，而其組成字常有重覆出現在不同詞內的情況，因此以某字為首而能形成的詞數有多有少，此數量即為所謂詞鄰項個數。在我們的研究中，清楚看到鄰項個數在凝視時間上的效果，顯示在詞彙處理過程中，鄰項詞確實會受到激發而有所影響；而本計畫的最佳凝視位置的實驗中，亦試圖瞭解是否凝視在不同組成字的位置上，會影響詞彙判斷所需的時間。在討論的過程中，他們不僅對中文詞的組成感到十分有趣，對於詞彙處理會受到組成字成詞可能性的影響，也提出一些過去英文研究的發現與解釋，對本計畫的實驗的後續分析與解釋，有很大的幫助。而雙方討論的另一個重點為中文關係子句的實驗，由於中文為head-final 的語言，因此在處理 subject relative clause (SRC)與 object relative clause (ORC)和英文在結構及所需的認知資源並不相同，而我們的實驗用眼動記錄了不同位置上的凝視時間及各種眼動指標，發現中文在處理 SRC 和 ORC 時，並不能單單從句子理解的結果來看其處理的難易程度，而是在句子的不同位置上，讀者面對並解決因語法模糊性而造成的問題，因此會得到不同的效果。對此，Garnsey 認為是非常重要的發現，在他們用按鍵逐詞呈現的作業上，並未發現和我們一樣有階段性的不同效果，但也同意若用眼動記錄的方式，較能符合日常閱讀的情境，而反應句法的處理歷程，未來將仔細比較雙方在實驗設計及材料的異同，結合 Garnsey 在語法課題上的專業學識，以及我們對中文句法的掌握與眼動實驗的進行，可針對中文關係子句處理相對於英文或其他語言的特殊性與普遍性，進行合作研究來共同探討此問題。

除了在 Garnsey 實驗室之外，亦有機會和其他老師一起討論，特別是心理系的

Kara Federmeier，雖然她的研究工具主要是ERP，但她的研究主題主要是和語意處理、脈絡、以及大腦半球處理有關，曾經使用眼動儀來探討語義處理與脈絡之間的交互作用，這和我目前另一研究主題探討脈絡對閱讀的眼動表現之影響有相當程度的關聯，同時她所採的實驗典範，也是目前我規劃中研究的方式，因此正好能藉此機會向她請教。此次美國研究交流的過程中，在個人目前及未來的研究課題上，獲得許多寶貴的建議及值得借鏡的想法，在合作研究上，也開拓了一些新的可能合作課題，也與國外學者有更多直接互動的經驗。整體而言，透過這次的參訪交流，不僅對進行中的研究有實質的幫助，所吸收的知識與經驗也非常充實且具啟發意義。

國科會補助專題研究計畫項下出席國際學術會議心得報告

日期：98年10月13日

計畫編號	NSC 96-2413-H-004-018-MY3		
計畫名稱	中文詞彙辨識的凝視位置效果之決定因素（第3年）		
出國人員姓名	蔡介立	服務機構及職稱	國立政治大學心理系助理教授
會議時間	98年10月9日至 98年10月11日	會議地點	中國大陸北京師範大學
會議名稱	(中文)第十三屆東亞語言處理國際會議 (英文)The 13th International Conference on the Processing of East Asian Languages		
發表論文題目	(中文)中文閱讀的眼動研究：詞頻與詞預測性效果 (英文)Effects of Word Predictability and Word Frequency on Eye Movements in Reading Chinese Sentences		

本次於2009年10月9日至11日參加在中國北京師範大學所舉辦的The 13th International Conference on the Processing of East Asian Languages (ICPEAL)。ICPEAL 的會議主題以東亞語言相關的心理語言學議題為主，涵蓋了字詞辨識處理的各個層次、句子處理的層次、口語理解與產出、雙語使用、以及語言發展等課題，過去參與的研究者及發表論文，主要是以中文研究為主，今年其他東亞語言，如日語或韓語，亦有學者與會，但發表的篇數仍然遠少於中文的研究；而中文研究的發表，台灣、香港、及大陸均有不少研究者參與並發表許多相關的中文研究。

在三天的會議中，共有５場大會演講，其中第一場演講講者為芝加哥大學的Steven

Small 教授，他本身具醫師背景，同時也是神經心理學的教授，研究專長為語言處理的神經生理機制，擔任 Brain & Language 期刊主編已有八、九年的時間。他的大會演講主要在說明語言處理與鏡像神經系統之間的關係，議題和觀點十分有趣，令人印象深刻。他在演講中介紹一些最新的研究證據，顯示大腦在語言處理的過程中，會引發一些和動作相關的運動大腦皮質的活動，同時這些活動亦對於語音處理與辨識有所助益，這點似乎說明了為何說話時常會搭配手勢或肢體動作。Small 教授亦提出觀點強調語言的理解，不單只建立在語言處理的機制上，同時也包括許多知覺、動作等等的表徵，都為理解的一部分。

會議期間共有 50 篇口頭論文報告和近 130 篇的海報論文報告，本次會議有相當數量的論文是用大腦事件關聯電位(ERPs)來進行，顯示 ERP 時間解析度的優勢確實為用來探討語言神經機制的合適工具，也突顯當今認知神經科學的研究工具已普遍地被應用在語言相關的課題，而本次 fMRI 的研究也不在少數。雖然本次會議眼動研究的論文不多，但其中德國 Kliegl 教授針對中文字為主與拼音文字以字母為主的眼動控制，提出許多研究證據來說明並檢驗當前主要爭論的課題。他認為中文文字系統的特性，如書寫單位（字）的豐富訊息，以及詞間沒有空白來標示邊界等特性，正合適用來檢驗當前不同的眼動與閱讀理論的爭議。而實驗取向的操弄文字刺激，或是用統計控制的語料大量眼動分析，分別可提供非常重要的佐證。此外，從演講中也清楚看到跨語言研究比較的優點，正是藉由語言或文字系統的差異，來瞭解不同語言相同與相異的處理機制，進而可釐清許多理論上的爭議或問題。

會議不少發表的論文是以中文雙字詞為探討對象，與本計畫的研究主題相符合，但並沒有看到與計畫中類似的操弄或方法，用最佳凝視位置的實驗典範來探討詞彙

組成訊息量分佈。其中有一篇眼動研究操弄雙字詞的語義透明度與詞頻，將目標詞放在句子中,以閱讀句子的方式來分析眼睛凝視在目標詞上的停留時間等眼動指標，但其結果並不一致且難以解釋。其他雙字詞的研究，大多在探討語義或組成字詞素的影響，探討的問題重點與使用的研究工具也各有不同。此外，有一些探討語言獲得和發展的研究也相當有趣，讓我們從學習的觀點，看到與語言有關的知識，如何透過語言使用的經驗累積，最後形成語言處理的機制，來處理語言的不同特性。整體而言，此會議相較於在歐美地區舉辦的心理語言學會議，最大的特色在於有非常多的中文研究，藉由參與此會議，與領域相關的學者有許多直接且深入的交流與討論，也能掌握目前中文研究領域的進展與討論的主要議題所在。

國科會補助計畫衍生研發成果推廣資料表

日期:2010/11/29

國科會補助計畫	計畫名稱：中文詞彙辨識的凝視位置效果之決定因素	
	計畫主持人：蔡介立	
	計畫編號：96-2413-H-004-018-MY3	學門領域：實驗及認知心理學

無研發成果推廣資料

96 年度專題研究計畫研究成果彙整表

計畫主持人：蔡介立　**計畫編號：**96-2413-H-004-018-MY3

計畫名稱：中文詞彙辨識的凝視位置效果之決定因素

成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	4	0	100%	千元	熊靜儀（2009）。中文詞彙辨識的鄰項週邊預視效應：文句閱讀的眼動研究。國立陽明大學神經科學研究所碩士論文。台北。台灣。 呂翠屏（2010）。語意在句法處理中的角色：中文關係子句的眼動閱讀研究。國立政治大學語言學研究所碩士論文。台北。台灣。 張雅嵐(97.9-98.7) 高佩如(98.9-99.6)
	參與計畫人力（本國籍）	碩士生	2	0	100%	人次	顏妙璇（2009）。中文句子閱讀中週邊詞彙處理歷程之眼動研究。國立陽明大學神經科學研究所博士論文。台北。台灣。 顏妙璇(97.1-98.6) 陳家興(97.1-98.2;99.1-99.6)
		博士生	1	0	100%		顏妙璇(98.7-99.6)

		博士後研究員	4	0	100%		曾筱匀(97.1-97.4) 許馨月(97.5-97.6) 熊靜儀(98.9-99.6) 林育稜(99.2.22-99.6)
		專任助理	0	0	0%		1. 協辦邀請法國科學院院士 Dehaene 教授來台演講(99.1.20) 2. 協辦邀請德國波茨坦大學Kliegl教授來台演講(99.5.17)

國外	論文著作	期刊論文	5	0	100%	篇	1. Yen, M. H., Tsai, J. L., Tzeng, O. J. L., & Hung, D. L. (2008). Eye movements and parafoveal word processing in reading Chinese sentences. Memory and Cognition, 36, 1033-1045. (SSCI) 2. Hsu, C. H., Tsai, J. L., Tzeng, O. J. L., & Lee, C. Y. (2009). Orthographic Combinability and Phonological Consistency Effects in the Reading of Chinese Phonograms: an Event-Related Potential Study. Brain and Language, 108, 56-66. (SCI) 3. Wang, C. A., Tsai, J. L., Inhoff, A. W., & Tzeng, O. J. L. (2009). Acquisition of linguistic information to the left of fixation during the reading of Chinese text. Language and Cognitive Processes, 24(7), 1097-1123. (SSCI) 4. Yen, M. H., Radach, R., Tzeng, O. J. L, Hung, D. L., Tsai, J. L. (2009). Early Parafoveal Processing in Reading Chinese

		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	2	0	100%		1. 韓承靜、蔡介立（民 97)。「眼球軌跡記錄—科學學習研究的明日之星」。科學教育月刊，310，pp. 2-11。 2. 韓承靜、洪蘭、蔡介立（民 99)。心像旋轉中之心智表徵特性－探討圖形複雜度與整合性的影響。教育心理學報(TSSCI），41，pp. 551-578。
其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)							

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數		

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：■已發表 □未發表之文稿 □撰寫中 □無

專利：□已獲得 □申請中 ■無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

本計畫利用操弄凝視位置的實驗典範，在單詞呈現的行為作業和閱讀文句的眼動表現，發現中文字詞辨識歷程中，組成字/部件的訊息量分佈會影響辨識的處理過程，且會受作業要求和組成單位的功能而有不同的影響。本計畫運用此特殊的實驗典範，首次有系統地直接證明凝視位置與字詞訊息量分佈之間的關係，此外，本計畫成果亦說明了字詞訊息量分佈對字彙辨識的重要性，可應用至學童學習詞彙時，若能強調字詞組成的訊息分佈，應對學習效率有所幫助；此外，針對閱讀困難的族群，亦提供另一個可能的重要影響因素作為其他應用研究之參考。