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Unconscious Grouping of Chinese Characters: Evidence from Object-based Attention*

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To show that, in reading, a fundamental and unconscious perceptual process occurs beyond the current fixation, we examined whether peripherally presented characters of Chinese words in such extreme viewing conditions could be grouped when some characters were rendered invisible while others were visible. We presented a pair of two-character Chinese words and indexed whether the visible and invisible characters that formed a word could be grouped together by the effect of same-object advantage—an index used to indicate the formation of perceptual grouping and the basis for attentional selection (i.e. object-based attention). Results revealed a difference in the judgments of prior entry that would otherwise be equivalent between two concurrent targets in a cued temporal-order judgment task: the target that appeared in the cued word was judged to appear first more frequently than the other target that appeared in the uncued word. The results suggest that a perceptual grouping was formed for two-character words between visible and invisible constituent characters. While grouping within two-character words occurred, the invisible characters remained invisible in most of the trials, suggesting that this grouping occurred unconsciously. This implies that, in reading, characters presented in the peripheral region can be grouped into words even without the readers' awareness of all the constituent characters, and such unconscious grouping can facilitate fluent reading by aggregating the texts into fewer meaningful units and thus reduce the number of fixations needed.

Key words: consciousness, continuous flash suppression, grouping, preview benefit, reading

1. Introduction

This study aims to demonstrate that there is an unconscious perceptual grouping of Chinese characters into words that directs the allocation of attention, the precursor of eye movements (Rizzolatti et al. 1987) that are essential for reading (Rayner 1998). To the best of our knowledge, no studies until now have shown unconscious grouping between constituent characters in a Chinese word nor its effect on allocation of attention. We suggest that this unconscious perceptual grouping assists the reading process because reading requires not only fixated characters but also peripheral ones, which, despite not being consciously legible, may nevertheless be grouped together to form meaningful units to affect attentional selection of them. Previous studies have shown that, during reading, words that are away from the current fixation or beneath our threshold of awareness are processed to a measurable degree (Henderson et al. 1995; McConkie & Rayner 1975; Rayner & Bertera 1979). Based on these findings, we demonstrate here that such processing provides the

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possibility of directing selective attention—selecting a subset of stimuli for detailed processing to prevent overwhelming the brain—by the unconscious grouping of constituent characters within words.

2. Unconscious processing of peripheral words

2.1 Preview benefit in reading

To examine how readers use foveal and parafoveal information, a gaze-contingent moving-window technique (McConkie & Rayner 1975; Rayner & Bertera 1979) has been used to limit the number of words that readers can see at a given time. The size of the window varies so that the number of visible words can be one (only the fixated word visible), two, or more. Any word outside the window is replaced with an 'X' to make the word inaccessible to the reader. Using this method, which limits the input information, participants are required to read aloud in order to measure their reading speed. The reading speed at the window size for three words was estimated to be 10% slower than normal reading (Rayner et al. 1982), suggesting that information at the peripheries is utilized.

With this moving-window technique, researchers have also examined the degree to which peripheral words are processed before they are actually fixated upon in the next saccade. It has been shown that, while the words presented in parafoveal regions are less identifiable than the fixated ones, several types of information from the words in the next fixation are preprocessed to a certain degree. Among them, orthographical, phonological, and semantic information of the parafoveal word can be preprocessed so that the fixation duration of the parafoveal word is shortened once the word becomes fixated (i.e. preview benefit) (Balota & Rayner 1983; Henderson et al. 1995; Rayner 1978; Yan et al. 2009, 2012).

2.2 Priming under visual crowding

Using a technique called visual crowding (Andriessen & Bouma 1976; Bouma 1973; Pelli 2008; Westheimer et al. 1976) to render the target unrecognizable to the observer, it has been shown that semantic information in the peripheral region can be processed without the involvement of participants' awareness of the words' orthography. In one recent study, Yeh et al. (2012) rendered unrecognizable a single-character Chinese word that was presented in the periphery by surrounding it with other non-words. The crowded target word was perceived within the jumble as 'something there', though it could not be identified and could not be classified as either a word or a non-word. Yeh et al. (2012) showed that the unrecognizable word produced a semantic priming effect on the subsequent target and that the amount of semantic priming was comparable to when the word was presented alone and recognizable to the observer.

3. Unconscious processing for invisible words during long suppression time

Placing words in an even more extreme position so that they were completely invisible to the observer, Yang & Yeh (2011) showed that emotional information could be processed in Chinese

words even when they were invisible. To obscure the words from awareness, Yang & Yeh adopted the continuous flash suppression (CFS) paradigm developed by Tsuchiya & Koch (2005), a paradigm that we also adopted in the current study. Specifically, Yang & Yeh (2011) presented emotion-describing and emotion-inducing Chinese words to one eye and a patch of colors as a Mondrian mask (similar to those presented in Figure 1) to the other eye, with the stimuli alternating between eyes every 100 ms. The Chinese words increased in contrast in the first 500 ms of the trial and remained at 50% contrast throughout the remainder of the trial. In this arrangement, the words could be maintained invisibly for quite some time (1–3 s). Participants were required to press a key as quickly and yet as correctly as possible to indicate their detection of the word and to localize the word (up or down) after the detection response. Only reaction times (RTs) for correct localization were analyzed. The results showed that, compared to neutral words, emotion-describing and emotion-inducing Chinese words required more time to break through the suppression and emerge into awareness. These results suggest that even invisible words that are suppressed from reaching awareness can be processed up to the semantic level.

4. Attentional guidance by perceptual grouping of characters

Previous studies have shown that perceptual grouping affects the allocation of attention (Egly et al. 1994; Kimchi et al. 2005; Palmer & Beck 2007; Wagemans et al. 2012). For example, using a pair of two-character Chinese words, Li & Logan (2008) showed that grouping between two characters of a Chinese word could form a perceptual grouping and guide attention.[1] Adopting the method used by Egly et al. (1994), Li & Logan (2008) presented a pair of two-character Chinese words around a fixation in such a way that the four characters occupied the four corners of an imagined square. To cue participants' attention (while their eyes were fixated at the center of the four black-inked characters on a gray background), the color of one of the characters was briefly changed from black to green. After that, as a target for detection, one of the four characters was changed from black to red. The participants needed to press a key as soon as they detected the presence of the target. Li & Logan (2008) found that the detection RT was shortest when the cue and the target coincided within the same character, confirming the spatial-cueing effect. More importantly, while the four characters formed two words, the detection RT for the target appearing in the uncued character belonging to the same word as the cued character was faster than the one for the uncued character in the other word, when both targets were equidistant to the cue. The advantage was said to result from the fact that the target was in the same word as the cue, an object-based cueing effect (Egly et al. 1994; Lamy & Egeth 2002; Shomstein & Yantis 2002). Hence, this result suggests that the two-character Chinese words used in their study formed perceptual groupings[2] and became the selection unit for visual attention in such a way that the cued word was processed earlier than the uncued one.

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[1] The two-character Chinese words used in Li & Logan (2008) were referred to as objects. In this study, though using similar measurements, we refer to these stimuli as perceptual groupings in a broad sense to avoid conflict or confusion with objects that are defined by connectedness and closure of contours.

[2] The grouping might form legal two-character Chinese words via orthographical, phonological, or semantic relatedness. However, this study focused on the possibility of unconscious grouping, not the relative contribution from each representation.

5. Goal of this study

In this study, we aimed to demonstrate that, without recognizing the constituent characters in a word, groupings occur between two peripherally presented characters of a Chinese word, and such an unconscious perceptual grouping serves as a basis for selective attention. Reading is by no means simple; it involves dynamic and complex processes from word recognition to sentence comprehension. Understanding perceptual and attentional processes in word recognition can contribute to the understanding of the essential and basic perceptual processes of reading. As is well known, eye movements are part of normal reading. Attention and eye movements are closely linked, and attention often shifts to a new location before the reader makes a saccade to that location (Deubel & Schneider 1996; Rayner et al. 1978; Shepherd et al. 1986). Therefore, examining the influence of unconscious perceptual grouping on attentional selection, as in this study, is informative about the reading process.

Because the words presented in parafoveal or peripheral regions are often less legible than the fixated one, to simulate reading conditions at the extreme ends, we rendered one character visible and the other invisible in the periphery. We reasoned that, if grouping occurs between two peripherally presented characters, it would also occur for the characters in actual reading situations where the visibility of the characters is higher.

We adopted the arrangement used by Li & Logan (2008) and indexed successful perceptual groupings using the performance of a temporal-order judgment task (Abrams & Law 2000; Shore et al. 2001), where participants judged which one of the two targets appeared first. The two concurrent targets appeared in the cued and uncued words. If one of the two simultaneous targets was judged to appear earlier than the other in a higher percentage of trials, it indicated that the judgment was biased by visual attention, which was guided by the grouping that occurred between two characters presented to two eyes. We further hypothesized that if grouping occurred in this arrangement between visible and invisible characters *without* the grouped word as a whole being visible, the grouping could be said to have occurred unconsciously. This was examined by an awareness check task that measured whether the invisible characters became visible after the temporal-order judgment task.

6. Experiment 1

In this experiment, initial characters (one from each of the two two-character words) were presented to the dominant eye (to be visible), while the remaining two characters were presented to the non-dominant eye (to be invisible). To render the characters invisible, we used the CFS paradigm (Tsuchiya & Koch 2005) by presenting Mondrian patches that refreshed every 100 ms (10 Hz) to the dominant (visible) eye to suppress conscious access to the stimuli by the other eye. In this way, the characters presented to the non-dominant eye could be suppressed and remained invisible for several seconds. Participants saw two characters from each of the two-character words on a background of dynamically changing colored Mondrian patches (Figure 1, top-right insets).

To cue participants' attention to one of the to-be-grouped words, the ink color of one character was briefly changed from white to red. Following that, with a pair of concurrent targets, a temporal-order judgment task was used to probe whether grouping occurred between visible and

invisible characters. We expected that, as long as the two-character words could be grouped from the characters presented to both eyes, the prior-entry results for the two concurrent targets should be different from chance level (50%). If the prior-entry percentages of two concurrent targets differed, it would suggest that the two perceptual objects (i.e. two words) were formed via grouping between respective characters for each pair of two-character words.

6.1 Method

6.1.1 Participants

Twelve National Taiwan University undergraduates participated in this experiment. All participants had normal or corrected-to-normal vision. The experiment was approved by the Internal Review Board of the Department of Psychology, National Taiwan University.

6.1.2 Apparatus

The stimuli were prepared and presented via a 21-inch cathode ray tube display (CRT, Eizo T966) with Windows XP using Matlab r2012b with Psychophysics toolbox extensions (Brainard 1997; Pelli 1997). The participants observed the display through a set of four mirrors (Tsuchiya &

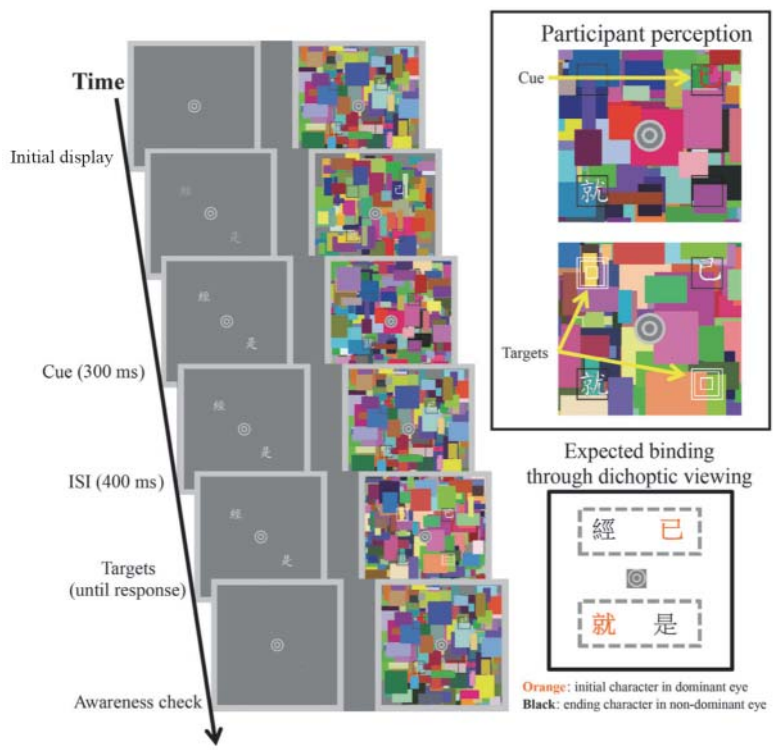

Figure 1: The procedure used in Experiment 1

Koch 2005) that helped them to fuse the left and right halves of the display. Each of their heads was stabilized on a head and chin rest that was placed 75 cm from the display.

The colorful Mondrian masks refreshed every 100 ms (10 Hz) to suppress the pattern shown in the non-dominant eye. The participants perceived the display in the dominant eye. After the cue (see inset at top right of Figure 1), the participants were required to report which of the two concurrent targets (top-right inset) appeared first by pressing the left or right button. Subsequently, the participants indicated whether they perceived the characters in the non-dominant eye (i.e. awareness check). The characters were parts of a pair of two-character Chinese words (bottom-right inset; all the characters were grey, and the dashed rectangles were not shown in the actual experiments). The imaged rectangles (i.e. the two words) were arranged either horizontally, as shown here, or vertically (not shown), with equal probability.

6.1.3 Stimuli

Eighty two-character Chinese words with a frequency of use ranging from 473 to 2,613 per 530,452 words were chosen (Lee & Tseng 1997; see Appendix A). Most of the two-character Chinese words selected were morphemically related (associative in nature), and some overlapped semantically. Four characters (i.e. a pair of two-character words, each character subtended 0.8° × 0.8°), separated by 6.8° from each other (center to center), were presented within placeholders (each subtended 0.8° × 0.8°, black) occupying the four corners of a virtual square (not shown in the actual experiment). To aid fusion, a fixation mark—a three-ring concentric circle (1° radius, grey, pixel value 196)—was presented to both the dominant and non-dominant eyes. The cue (ring of 1°, red, pixel value R = 255, G = B = 0) and the targets (two concentric squares, 1° × 1° each; Figure 1, top-right inset) were presented only to the dominant eye. While the two-character Chinese words were arranged in such a way that the visible and the invisible parts of a word could be grouped, sometimes interference arose from occasional groupings between the visible characters that belonged to different words (and perhaps between the invisible characters too). Nevertheless, the influence of such interference could be ignored because the task performance was affected by the expected grouping between visible and invisible characters.[3]

6.1.4 Procedure

The participants were asked to keep their eyes on the fixation point throughout the trial. At the beginning of each trial, the two visible characters were presented at the highest luminance pixel value (i.e. 255). The other two characters in the non-dominant eye increased contrast linearly every 1.6 seconds, relative to the background luminance in the initial display, to 20% brighter than the gray background at the cue display, and remained so. After that, the cue was presented in one of

[3] The relative strength of grouping between visible–visible and invisible–invisible characters is interesting and of theoretical importance. However, it is beyond the scope of the current study, which aims to demonstrate unconscious grouping between visible and invisible characters.

two visible characters for 300 ms. After an inter-stimulus interval (ISI) of 400 ms in the dominant eye, the targets were presented concurrently in two placeholders that were diagonal from the one occupied by the cue.[4] The participants were asked to press the left ('z') or right ('/') key to indicate which target appeared first (i.e. a temporal-order judgment task). After their response, the contrast of the characters in the non-dominant eye was decreased to zero within 800 ms, and then an awareness check was performed. A question ('Did you see anything else?') was displayed at the upper part of the display, and the participants responded whether they saw the characters in the non-dominant eye by pressing yes ('z') or no ('/'). To ensure that the awareness check could be performed, the participants needed to know what the content in the non-dominant eye looked like. Therefore, before the practice session (see §5.1.5), the participants were instructed to close their eyes one at a time to see the display in the dominant and non-dominant eyes respectively. Those trials with a 'yes' response in the awareness check were excluded from further analysis.

6.1.5 Design

The cue could appear at any one of the four corners with equal probability in the dominant eye, while the two targets always appeared on a different diagonal than the cue. The two-character words could be formed either horizontally or vertically, with equal probability of either option. The order of the trial presentation was randomized for each participant. To maintain the relative spatial relation of cues, targets, and invisible characters, the reading directions for the two words differed so that, in the horizontal configuration (Figure 2), one word would be read from the left and the other from the right. Similarly, in the vertical configuration, one word could be read from the top and the other from the bottom. The experiment consisted of a practice session of 30 trials and a formal session of 160 trials. Trials were categorized by participants' responses: If the target in the cued word was judged to appear first, the trial would be labeled as a *same-object* target trial. If the other target in the uncued word was judged to appear first, the trial would be labeled as a *different-object* target trial. To determine whether interocular grouping occurred, the percentage of same-object target trials was examined against chance level response (50%, meaning the two concurrent targets were judged to appear first equally often).

6.2 Results

In the awareness check, the characters presented to the non-dominant eye were not seen in 78% of the total trials, and only these trials were subject to further analysis regarding whether grouping occurred unconsciously.

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[4] The presentation and arrangement of the four characters were controlled spatially and temporally. Spatially, the four characters were arranged equidistant from each other, and thus grouping based on spatial proximity did not confound the results. Temporally, the visible characters were presented all together from the beginning of the trials, and the contrasts of the two invisible characters were ramped up at the same pace and by the same amount. Thus, grouping among the four characters based on spatial or temporal co-occurrence was less likely to occur.

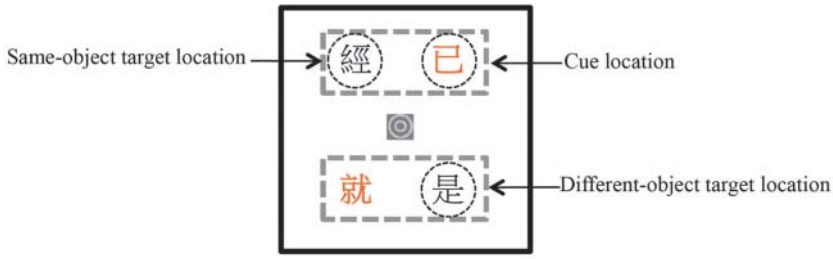

Figure 2: Stimuli of Experiment 1. Dashed circles indicate respective locations for cues and targets relative to the grouped words. Dashed circles and rectangles were not shown in the actual experiment.

To examine whether the sudden onset cue would bias attentional spreading in a specific direction, a two-way analysis of variance (ANOVA) using cue location (four locations) and grouping orientation (horizontal, vertical) as factors was performed on the percentage of same-object target trials. The results showed no main effect of either cue location ($F(3, 33) = 0.042$, $p = 0.988$) or grouping orientation ($F(1, 11) = 0.751$, $p = 0.405$). The interaction was not significant ($F(3, 33) = 2.881$, $p = 0.051$). This analysis suggested that there was no spatial bias in response to peripherally presented cues in either grouping orientation.

The evidence that unconscious grouping occurred between characters presented to both eyes was supported by the fact that the proportion of same-object target trials was more than chance level (53.2%; $t(11) = 2.72$, $p = 0.018$, Cohen's $d = 0.69$). This indicated that the two-character Chinese words were formed between constituent characters presented to separate eyes so as to affect the order of appearance of the concurrent targets: the target in the cued word was judged to appear earlier than the target in the uncued word. These results were based on the majority of trials that remained invisible, suggesting that even when grouping occurred between a visible character and an invisible character of a two-character word, such grouping did not lead to the emergence of consciousness for the grouped words in these trials. Hence, we suggest that such grouping occurs unconsciously.

In this experiment, the visible characters were the initial characters and the invisible ones were the ending characters of the two words. This arrangement suggested that, in reading, unconscious grouping occurs between characters seen in the current fixation (visible) and those away from it (invisible). While reading is sequential and directional, in normal reading, it is also possible that we fixate on an ending character while the initial character falls far left of the current fixation, rendering the initial one less legible. To show that unconscious grouping also occurred between the current fixated ending character and the initial character in the previous fixation, in the next experiment character combinations were randomized so that either initial or ending characters of a word could be presented to the dominant eye.

7. Experiment 2

To simulate the grouping of characters between the current fixation and the previous one, in this experiment either initial characters or ending characters of a word could appear in the dominant

eye and thus be visible. Meanwhile, the other two characters of the two-character words were kept invisible to the non-dominant eye.

7.1 Method

7.1.1 Participants

Twelve National Taiwan University undergraduates participated in this experiment. All participants had normal or corrected-to-normal vision.

7.1.2 Stimuli, apparatus, procedure, and design

While most of the arrangements in this experiment were the same as those in Experiment 1, the design was different from Experiment 1 in the following aspects. There were 240 trials in total. There were 60 trials (compared to 160 in Experiment 1) in which initial characters were visible (i.e. the *both initials visible* condition; see Figure 3) and 60 trials in which both ending characters were visible (i.e. the *both endings visible* condition). For the rest of the 120 trials, the initial character of one word and the ending character of the other word were chosen to be visible (i.e. the *initial and ending visible* condition). To maintain the relative position of cues, targets, and invisible characters the same as in Experiment 1, the reading directions for words in the *both initials visible* condition differed from each other; the reading directions were the same for words in the other two conditions (Figure 3).

7.2 Results

In the awareness check, the characters presented to the non-dominant eye were not seen in 85% of the total trials and were subject to further analysis.

Similarly to Experiment 1, to examine whether the sudden onset cue would bias attentional spreading in a specific direction, a two-way ANOVA using cue location (four locations) and grouping orientation (horizontal, vertical) as factors was performed on the percentage of same-object target trials. The results showed no main effect for either cue location ($F(3, 33) = 0.724$, $p = 0.546$) or grouping orientation ($F(1, 11) = 3.612$, $p = 0.084$). The interaction was not significant ($F(3, 33) = 1.215$, $p = 0.329$). Again, no spatial bias in response to peripherally presented cues in either grouping orientation was found.

The rest of the trials were analyzed using a one-way ANOVA with the factor of character combinations (both initials visible, both endings visible, and initial and ending visible), using the proportion of same-object target trials as the dependent variable (50.5%, 54.4%, and 53%, respectively). No significant difference was found between the three conditions of character combinations ($F(2, 22) = 1.421$, $p = 0.2691$) and, therefore, the conditions were merged to test against chance level (50%) to examine the existence of same-object advantage. The results showed that the proportion of same-object target trials (52.7%; see Figure 3) was more than chance level ($t(11) = 2.5$, $p = 0.029$, Cohen's $d = 0.61$). That is, same-object advantage was obtained.

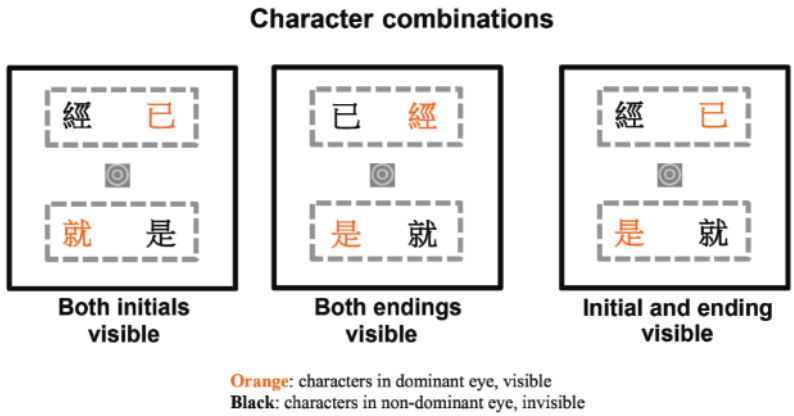

Figure 3: Stimuli of Experiment 2. Characters in orange were presented to the dominant eye and visible. Dashed rectangles were not shown in the actual experiment. In the both-initials-visible combination (left), orange characters denoted the initial characters for two words that were visible, while in the both-endings-visible combination (middle), orange characters denoted the ending characters from two words. Thus, in the initial- and ending-visible combination (right), the upper orange character was from the initial part of a word and the lower orange character was from the ending of a word.

This experiment showed that, by presenting visible ending characters and invisible initial characters to simulate grouping between current and previous fixations, we obtained the same results as in Experiment 1, where initial characters were made visible and ending characters invisible to simulate grouping between current and next fixations. This suggests that grouping between characters in a two-character word is a general phenomenon and that such grouping is not restricted to the current fixation and the next one; it also occurs between the current fixation and the previous one.

8. General discussion

In two experiments, we showed that grouping occurred between two peripherally presented characters, each belonging to a two-character Chinese word, and the two words were presented in such a way that one character was visible and the other invisible. In Experiment 1, when the initial characters of both words were visible, the proportion of same-object targets was more than chance level (i.e. the same-object advantage). In Experiment 2, when either one of the two characters of a word was chosen to be visible, the same-object advantage was obtained again. Taken together, these results showed that grouping occurs between visible and invisible peripheral characters of a two-character word. Based on this finding, we suggest that, in normal reading, grouping between characters within words occurs not only between the current fixation and the next one, but also between the current fixation and the previous one.

Although in this study the participants' eye movements were not monitored, this should not affect our conclusion for two reasons. First, the concurrent targets (unknown to the participants),

which were equidistant to the fixation and to the cue, imposed a high task demand for the participants to *correctly* identify the prior entry. Thus, by design and by being advised, the best strategy for the participants was to have their eyes fixated on the fixation point. Even if the participants were indeed attracted and moved their eyes toward the sudden onset cue, subsequent targets were still equidistant regarding the cued location. Second, the task of temporal-order judgment required the participants to judge the order of the onset that occurred only at the instant of (concurrent) appearance of the two targets. After that instant, subsequent unconstrained eye gaze would provide no information about the onset (nor the offset, which occurred only after the participants made their judgment).

What we found here suggests that fluent reading gains support from perceptual processes that group characters into perceptual objects (words). Previous studies showed that when readers' eyes move onto a word, the landing location of their eyes is located between the beginning and the middle of the word, either on a preferred (Rayner 1979) or an optimal viewing location (O'Regan & Lévy-Schoen 1987). In English, because empty spaces define word boundaries that are clear in text, it makes sense that saccadic eye movements land on particular locations (either preferred or optimal ones) in words. However, empty spaces do not work in defining word boundaries in Chinese. The unconscious grouping we found provides a basis for determining the preferred/optimal viewing location in the sense that the basic unit of a word is grouped across the empty spaces between characters of a multi-character word unconsciously before eye movements. Consequently, such grouping decreases the number of fixations needed from the empty-space-delimited landing sites for eye movements to the landing sites defined by words grouped across empty spaces.

The spatial extent of unconscious grouping we found is compatible with the estimation derived from the moving-window technique. While the moving-window technique requires participants to read, our method requires only that the participants judge concurrent targets appearing in the grouping between visible and invisible characters. In this way, we obtained groupings between characters 6.8° apart, a similar width compared to those found with reading in the moving-window technique (Schotter et al. 2012). Meanwhile, the unconscious grouping we found, though it was not aimed at measuring the speed of reading under restricted circumstances, as in the moving-window technique, suggests a possibility that eye movements during reading are not only affected by factors measured with methods of conscious accessing (e.g. reading), but are also affected in an unconscious way that may account for the 10% slower reading in the moving-window technique (Rayner et al. 1982). That is, the unconscious process we found might contribute to reading by forming objects (the words) upon which attention can be selected before eye movements are executed. Such preceding selection by attention may in turn facilitate saccadic eye movements to the next word.

Previous studies using the priming paradigm have shown processing of invisible words (Forster & Davis 1984; Marohn & Hochhaus 1988; Rugg 1987; Yang & Yeh 2011), and what we found here added the dimension of spatial relations as well. In priming (e.g. Forster & Davis 1984), when a brief prime (about 50 ms in duration) followed a pre-mask and was followed by a target, participants often reported not seeing the prime, and yet their response was affected by the prime. Priming occurs sequentially and is often explained in terms of pre-activation and then activation of the same node in a network of words that codes their relatedness in terms of distance between the nodes (e.g. Collins & Quillian 1969). By explaining our findings in such a network, there is a connection built between the visible and invisible words we presented. In addition to such a connection, what we

found also indicates that the grouping of characters might be achieved by binding between activation of the visible and invisible characters in such a way that the spatial relations of the characters (horizontally or vertically oriented) are also included in the binding. This inclusion of spatial relations might be achieved by the feedback from nodes of the network to low-level representations in early perceptual areas where precise location information of characters is stored.

Although further studies directly manipulating this factor are needed, high-frequency words used in this study might facilitate the build-up of expectations upon seeing the visible parts of the cued word via their associative nature. For example, seeing the initial character 已 of 已經 (which means 'already') being cued might also prompt the participants to expect the presence of 經 because only a few characters form a word with the character 已. Despite participants' not actually seeing that character (經) presented to the suppressed eye, such expectations might, along with the perceptual process that formed the objects based on semantics, facilitate the participants' attending to the cued word rather than the uncued one. Further studies are needed to discover the relative contribution of such expectations and the perceptual process in forming such semantic objects.

One might be interested to try to discover the nature of the representation that supports such grouping in this study to understand normal reading; however, this study is better appreciated from the perspective of processing aspects of a mechanism rather than the representation aspect. This is because a word can be represented by orthographic, phonetic, and semantic forms, and the interaction and relative importance of each component to word recognition is still under debate. Further studies would be necessary for our line of research to address the relative contribution of each form of representation for unconscious grouping. On the other hand, with linguistic stimuli we find that attention is influenced by unconscious grouping before eye movements, and this finding contributes to the understanding of normal reading in a similar fashion to the use of the moving-window technique—both contribute to the understanding of normal reading in terms of the process.

Given the close relationship between attention and eye movements, it would be interesting to compare the spatial extent of the unconscious grouping that we have demonstrated and the findings from moving-window studies. For example, the separation between characters in this study is about the same as that of the maximum moving window used in previous studies. The characters were separated 6.8° in our study, while the maximum moving window was about 7° according to Figure 1 of Schotter et al. (2012) and Table 1 of Rayner et al. (1982). It would not be surprising if we found unconscious grouping with smaller separations, although this awaits further empirical tests.

Using this novel method to examine unconscious grouping between peripherally presented characters of two-character words, what we have found here advances our understanding of reading in terms of the attentional process that occurs before eye movements as required by normal reading. That is, though the current study is not the only one that shows parafoveal processing without awareness, as far as we are aware ours is nevertheless the first one to demonstrate the potency that unconsciously grouped words can to the best of our knowledge serve as a perceptual object for attention to select upon before saccadic eye movements are executed. This potency, we suggest—though future experiments are needed—may exist not only for Chinese but also for other languages.

Appendix A: Stimuli used in this study

Chinese word	Meaning	Chinese word	Meaning	Chinese word	Meaning
我們	we	時間	time	投資	investment
臺灣	Taiwan	市場	market	就是	exactly
可以	able	朋友	friend	關係	relationship
自己	self	公司	company	未來	future
他們	they	電影	movie	重要	important
沒有	without	兒童	children	出現	appear
因爲	because	中國	China	引擎	engine
可能	possible	由於	due to	希望	hope
如果	if	所以	so	研究	study
問題	question	知道	know	北市	Taipei
因此	hence	現在	now	學生	student
生活	life	許多	many	設計	design
什麼	what	政府	government	時候	moment
工作	work	發現	discover	文化	culture
孩子	kid	成爲	become	表現	performance
美國	America	教育	education	國家	country
廣告	advertisement	雖然	although	發生	occurrence
經濟	economy	認爲	think	安全	safety
社會	society	企業	enterprise	進行	undergo
活動	activity	地方	local	其他	other
開始	begin	必須	must	環境	environment
大陸	continent	如何	how	表示	show
世界	world	目前	current	無法	unable
日本	Japan	不過	however	方式	manner
國小	elementary school	影響	influence	國內	domestic
但是	but	已經	already	需要	need
發展	development	政治	politics		

Note: Gray shading indicates that the constituent characters of the word overlap semantically. Otherwise, where there is no shading, there is an associative relationship between characters.

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中文字的無意識整合：來自物體爲基注意力的證據

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我們藉由檢驗在視野邊緣呈現的中文雙字詞是否能在部分單字不可見時整合，來展現在閱讀中一個發生於目前凝視點之外的無意識知覺歷程。我們呈現兩個雙字詞，並且藉由同物效果，一種用來作爲知覺組織形成以及注意力選擇（亦即，物體爲基注意力）的指標，來探討雙字詞的可見與不可見單字之間是否能夠整合。實驗結果顯示，在先後判斷作業中，兩個同時出現的目標被判斷孰先孰後的比例不同：在被注意力提示過的雙字詞上出現的目標比較常被判斷爲較早出現。這樣的結果顯示，當雙字詞的兩個單字一個爲可見，另一個爲不可見時，知覺組織仍然可以形成。在知覺組織形成之時，雙字詞中的不可見單字仍然維持不可見，顯示知覺組織在無意識下完成。這結果暗示了，在閱讀中，在視野邊緣的單字可以在不需要讀者對於所有組成字有意識的情形下組織成字詞。而這樣的無意識整合可以藉由將文字預先聚合成較少的有意義單元以減少所需要的凝視點數目而促進閱讀的流暢性。

關鍵詞：閱讀，預視效果，持續閃現抑制，整合，意識