

Change Detection and Chinese Characters: The Reader Advantage

**by
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Abstract

The change-detection task can be used to assess how efficiently individuals perceive visual information. While reading ability allows us to efficiently recognize written characters, little is known about whether it also facilitates detection of changes to these characters. Three experiments were conducted to investigate this question. Participants saw many Chinese characters or Chinese-like artificial characters in flickering images and were required to find the one that was changing. Chinese readers were faster than non-readers when detecting changes to Chinese characters, but there was no difference between the performance of readers and non-readers when detecting changes to meaningless artificial characters. Also, readers detected changes faster when all of the unchanging characters were Chinese, and slower when they were artificial. These findings demonstrate a reader advantage when detecting changes to Chinese characters. That is, readers' ability to differentiate meaningful and meaningless written characters allowed them to detect character changes more efficiently.

Keywords: Change detection; Flicker task; Chinese character; Reading

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Introduction

The ability to notice relevant information and changes in the visual environment is critical to everyday task performance. But, surprisingly, this ability is sometimes quite limited. One often-cited demonstration of this was an experiment in which observers watched two different videos superimposed on the same viewing screen (Neisser & Becklen, 1975). When asked to focus their attention on and monitor events in one of the videos, observers often failed to notice events in the other video that they were not paying attention to. This is particularly compelling because the unattended visual events were directly in the observers' line of sight. This shows that gazing at an object does not necessarily mean it will be consciously perceived unless it is also attended to. Failure to notice unattended objects directly in our line of sight is known as inattention blindness (Mack & Rock, 1998a, 1998b). Other researchers noted that when attention is not focused on objects, not only are they less discriminable than attended objects, but we might even fail to notice significant changes to their appearance (e.g., Jensen, Yao, Street & Simons, 2011; O'Regan, Rensink & Clark, 1999; Rensink, O'Regan & Clark, 1997). This is referred to as *change blindness* (see also, Simons, 2000; Simons & Rensink, 2005). The change blindness phenomenon suggests that the detection of visual changes is not as straightforward as it seems.

Change Detection and the Flicker Task

Eye movement researchers were among the first to study the perception of visual changes (Rensink, 2002; Simons & Levin, 2003). When observers inspect a visual scene, they typically make rapid eye movements called saccades, which are carried out to focus objects of interest onto the highly sensitive foveal region of the retina. While the eyes are in motion during saccades, there is a dramatic deterioration of visual sensitivity called *saccadic suppression* (Matin, 1974). It occurs just before (~75 ms) the eyes start to move, is strongest at the beginning of the movement, and weakens once the eyes have landed in their new position. This suppression does not prevent stimuli from being processed by the visual system, but it does appear to be associated with reduced perceptual awareness (Krekelberg, 2010; Watson & Krekelberg, 2009). During a saccade, individuals are far less aware of stimulus movement and the onset of visual probes (Bridgeman, Hendry & Stark, 1975; Latour, 1962; Volkman, Schick & Riggs,

1968; Zuber & Stark, 1966). Previous research suggests that the perceptual impairment associated with saccadic suppression can lead to difficulty in detecting changes that occurred during the saccade. McConkie and Zola (1979) conducted an experiment in which observers saw words in alternating upper and lower case while their eye movements were being monitored. Once their eyes were in motion during a saccade, every letter was switched to the opposite case (e.g., aNaTOMY changed to AnAtoMy) and, surprisingly, most observers did not notice the change. Grimes (1996) used a similar technique, but with photographic images. When some aspects of the currently viewed image were altered while the eyes were in motion during a saccade, observers were often unable to detect changes. The saccade-contingent method was one of the first techniques used to study change detection.

In the late 1990s, a different task was developed by Rensink and colleagues (1997) to study change detection without tracking observer's eye movements. It involves the presentation of the original version of a stimulus (image A) and then a modified version of that stimulus (image A'). Between the presentation of image A and A', there is a briefly presented blank field that masks the transients associated with the change, thereby preventing attention from being drawn to the change location. When shown in continuous alternation, the stimulus presentation is essentially a 4-frame movie that loops. In Rensink et al.'s (1997) experiments, for example, the original image A was presented for 240 ms, followed by a blank field for 80 ms, followed by the modified image A' for 240 ms, followed by another blank field for 80 ms, followed by the original image again, and so on until a response was made or the trial ended (see Figure 1). This is known as the *flicker task*. When performing this task, observers saw what appeared to be a flickering photo, and were asked to find the changing object within it. The changing object is referred to as the "target". The flicker task is commonly used to study factors related to change blindness and change detection, partly because it does not require complex instrumentation involving eye tracking.

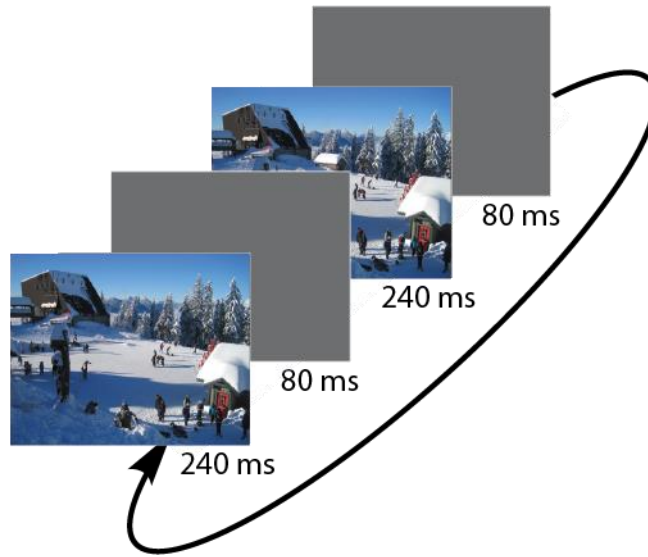


Figure 1. An example of the flicker-task stimulus presentation sequence.

In order to detect the change while performing a flicker task, observers need to attend to the target location and compare the perceived information between image A and A' (Jensen et al., 2011; Rensink, 2002). But observers rarely notice the changing target right away. Instead, they usually need to serially inspect a number of different locations within the stimulus display before the target is found. Serial search for targets within flickering displays is similar to search for targets within static (non-flickering) stimulus displays (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Wolfe, 1998, 2016; Wolfe & Horowitz, 2017). For example, with both flickering and static displays, serial search can be associated with a significant set-size effect (i.e., time required to serially search the display and find the target increases as the number of non-target objects in the display increases) (e.g., Rensink, 2000a). In addition, with both types of displays, the presentation of a location cue indicating the probable target location can facilitate search efficiency (e.g., Scholl, 2000). Hence, most aspects of serial search within static-displays also hold for serial search within flicker-displays.

Despite some similarities, there is a critical difference between the flickering- and static-display experiments. In static-display experiments, observers usually search for a pre-defined target, and indicate whether it is present or absent. When searching within a static display for a known target, the observer compares each inspected item with a mental representation of the target to determine whether they match. If so, then the target has been located and the search is terminated. If not, then search resumes at another location. In a flicker-display experiment, however, observers are not given any

specific information about the target's identity. Instead, they are able to find the target because it is the only item within the display that "changes". Consequently, when searching within a flicker-display for the changing target, the observers have to compare each inspected item at particular location with itself to detect the "change". That is, the observer must compare the identity of the currently focused item in image A with the identity of the item at the same location in image A' (see Figure 2). If they do not match, then the changing target has been located and search is terminated. But if they do match, then the item is not the target, and serial search continues at another location. The next item's identities in image A and A' are again compared to determine a match/mismatch, and so on. In other words, whereas search within static displays typically involves inter-item comparisons, search within flickering displays, in a sense, involves intra-item comparisons.

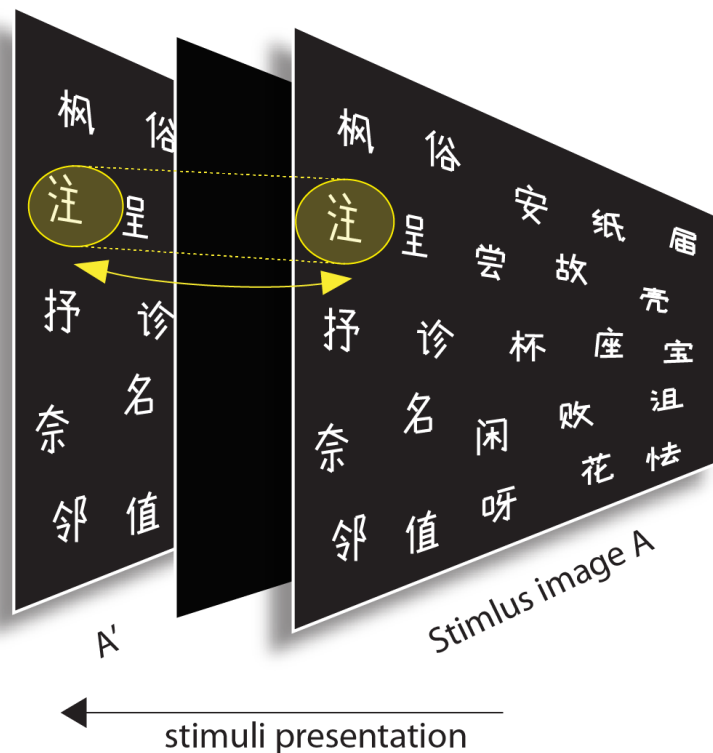


Figure 2. The flicker-task search algorithm involves comparing items in image A with the items at the corresponding locations in image A' to determine whether they match or not.

Many of the flicker-task studies conducted since 1990s used pictorial stimuli (usually photographs) because they are particularly suited for studying how we attend to natural scenes (e.g., Rensink et al., 1997). But their use also limits the degree of control

that experimenters have over important aspects of search tasks. For example, objects within pictorial scenes often differ in size, shape, and colour. And these objects almost always differ in their relative interest to observers, which can bias search. More specifically, changes to central-interest objects tend to be detected faster than changes to marginal-interest objects, which indicates that search is often biased toward the locations of the former (e.g., O'Regan, Deubel, Clark & Rensink, 2000). Objects in non-pictorial displays, on the other hand, can be created so that the experimenter has more precise control over size, shape, and colour. And the objects' relative "interest" to observers can also be controlled. Another limitation of pictorial stimuli is that objects within scenes (particularly central-interest ones like people) tend to be located somewhere closer to the centre of the display. Therefore, over trials, observers may develop a strategic bias to begin searching near the centre. In contrast, non-pictorial stimuli are not constrained by photographic composition, and the positions of individual items can be randomized over trials so that targets are equally likely to appear at central and peripheral locations within the display. Thus, pictorial stimuli are most suitable for studying how aspects of visually-rich natural scenes such as gist and context affect search for objects within them. But non-pictorial stimuli allow the experimenter to have more precise control over object features and locations, and these stimuli are most suitable for studying how stimulus properties affect search efficiency.

Reading and Change Detection

Change detection is influenced by lower-level visual properties of targets such as colour, size, and orientation (e.g., Rensink, 2000a; Shi & Wright, 2016; Smilek, Eastwood & Merikle, 2000; Tovey & Herdman, 2014; Wright & Shi, 2017). And it is also influenced by higher-level factors such as familiarity with the objects in the display (e.g., Buttle & Raymond, 2003; Tovey & Herdman, 2014), and observers' experience and expertise with objects (e.g., Clark, Fleck & Mitroff, 2011; Sheridan & Reingold, 2014; Werner & Thies, 2000). But one type of expertise—reading—has not been examined by change detection researchers. Reading ability develops through intensive practice at learning to recognize and retrieve the meaning of the written words and characters. It is associated with a visual expertise at processing words (Björnström, Hills, Hanif, & Barton, 2014; McCandliss, Cohen & Dehaene, 2003). To my knowledge, however, no study has been conducted specifically to determine whether or not reading ability can facilitate

change detection to written words. The aim of the current study was to address this question.

To examine the effect of reading ability on change detection, I conducted a series of experiments with linguistic stimuli. Chinese characters were chosen because they are uniquely suited for use as stimuli in the flicker change-detection experiments. These characters are square-shape logograms and most are composed of 7 to 12 strokes (lines, dots, curves) (Luo, Chen & Zhang, 2017). The strokes are grouped together to form one or more orthographic components called radicals (see Figure 3). The characters are also similar in shape and size, regardless of the number of strokes they are composed of (Goonetilleke, Lau & Shih, 2002; Tang, Au Yeung, & Chen, 1997; Yeh, Li, Takeuchi, Sun & Liu, 2003). Relative to Roman alphabet letters, Chinese characters are visually complex and can be modified in a number of different ways. Their small square shape also eliminates the need for left-right (or vice versa) scanning that may occur with alphabetic word stimuli. Whereas English words unfold linearly in one dimension, Chinese characters have a two-dimensional form with several possible spatial structures (Sun, Yang, Desroches, Liu & Peng, 2011). Moreover, unlike alphabetic letters, Chinese characters are morphemic. They can be used to study potential effects of linguistic meaning on search. Thus, Chinese characters are ideal for testing the questions raised in the current study.



Figure 3. Examples of Chinese characters. They are made up of strokes and radicals, and are morphemic. The dashed sections represent radicals within each character.

Orthography is a set of rules and conventions associated with a writing system (Richards, Platt & Weber, 1985). Chinese orthography specifies the rules of radical composition and position when configuring a character (Chen, Allport & Marshall, 1996; McBride, 2016). Knowledge of Chinese orthography is generally developed through literacy acquisition, and it is one way to determine whether or not a character is Chinese (e.g., Ho, Yau & Au, 2003; Luo, Chen, Deacon & Li, 2011; Wang & McBride, 2016). One technique that has been used to study readers' knowledge of visual orthography is the

lexical decision task (see Meyer & Schvaneveldt, 1971). The term "lexical categories" refers to the division of words into different classes (e.g., nouns, verbs). And the most basic division of lexical categories is that between words and non-words. In Chinese, a similar basic division of lexical categories is between real and artificial characters (e.g., Chen et al., 1996; Lee, Huang, Kuo, Tsai, & Tzeng, 2010; Liu et al., 2013; Tzeng, Hsu, Huang, Lee., 2017; Tzeng, Hsu, Lin, & Yang, 2018; Wong et al., 2012). This difference is mostly orthographical. Artificial characters typically contain orthographically illegal components, or illegal positions of orthographically legal components (e.g., Peng, Li & Yang, 1997; Tzeng et al., 2018). Beginning readers have a limited knowledge of orthography, and are less aware of the difference between real and artificial characters (Shu & Anderson, 1999; Tzeng et al., 2017). Skilled readers, on the other hand, can efficiently identify artificial characters (e.g. Shu & Anderson, 1999; Peng et al., 1997). As readers become more skilled, their recognition of Chinese may involve holistic processing of the overall configuration of characters as opposed to processing of constituent strokes or radicals (e.g., Chen & Yeh, 2015; Chua, 1999; Su & Samuels, 2010; Wong et al., 2011a, 2011b; Yeh et al., 2003; Zhao, Qian, Bi & Coltheart, 2014). And Chinese character recognition requires a greater degree of visual orthographic knowledge than Roman alphabet letter recognition.

The purpose of the current research was to determine whether or not reading ability would have any effect on the detection of changes to Chinese characters. I compared the flicker-task performance of participants who could read Chinese with that of participants who could not. I expected to find that readers would be able to detect Chinese-character changes faster than non-readers, and that the results of the experiments would provide some clues about how readers perceive Chinese characters differently than non-readers.

Experiment 1

This experiment was conducted to determine whether or not Chinese readers would detect changes to Chinese characters faster than non-readers.

Method

Participants

Forty-nine Simon Fraser University (SFU) undergraduate students were recruited through the Psychology Department Research Participation System. They received course credits in exchange for their participation. In addition, three SFU undergraduate students were recruited through advertisements posted on bulletin boards at various locations around the campus. These students received a \$5 gift card in exchange for their participation. All participants had normal or corrected-to-normal vision, and had no history of seizure. Of the 52 participants, 26 self-reported to be proficient Chinese readers, and 26 self-reported to have minimal or no experience reading Chinese. The ages of participants in the Chinese-reader group ranged from 18 to 25 years ($M = 20.5$ years, 22 females). The ages of participants in the non-reader group ranged from 18 to 24 years ($M = 19.1$ years, 21 females). This study was approved by the SFU Office of Research Ethics.

Apparatus

All experiments in this study were carried out with Dell PC computers and 19" Samsung SyncMaster 932 BF LCD monitors (1240 x 1028 px display resolution). Participants' viewing distance in each experiment was 60 cm from the monitor. The experiments were controlled by and responses were recorded using E-prime 2.0 software.

Stimuli

Each stimulus display contained 25 different characters. They were white (rgb 255, 255, 255), and presented on a black background (rgb 0, 0, 0). Characters were roughly square in shape, and were about $3.3 \times 3.8^\circ$. They were custom-made with

Adobe Illustrator graphics software so that their component strokes could easily be altered. Each one was composed of 8 to 11 straight lines and was clearly recognizable as a Chinese character by proficient readers of simplified Chinese (see Figure 4). The set of characters presented on each trial was randomly drawn from a pool of 488. Roughly equal numbers of 8-line, 9-line, 10-line, and 11-line characters were presented on each trial, and they were positioned throughout the screen in a 5x5 array (27.6 x 27.6°). More specifically, each character was positioned within one of the 25 imaginary position grids (5.52 x 5.52°). In order to make the search task more challenging and to vary the appearance of stimuli across trials, their positions were slightly “jittered” within the grid so that the characters were never in straight rows and columns. Also, adjacent characters within the display never formed meaningful word pairs or sentences that could be read by participants. Over the course of the experiment, there was an equal likelihood that the target would be presented at any of the 25 locations within the 5x5 stimulus array.

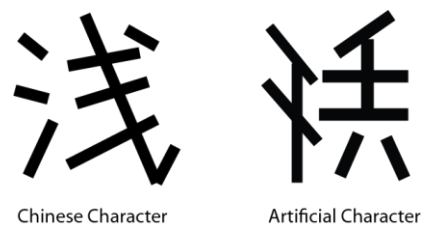


Figure 4. Example of straight-line Chinese and artificial characters used in this study.

As mentioned previously, the flicker task involves the rapid alternation of two similar but slightly different stimulus images. These images (A & A') are identical except for the object at the change location. In this experiment, 24 of the 25 characters were the same in both images. Only one character, the target, differed at a given location within the two images. More specifically, in image A', a subset (3 or 4) of the target character's component lines was altered. I refer to this type of alteration of the target as *partial change* because the target's other component lines were still the same in both image A and A'. As a result of this partial change, the altered target character in image A' was no longer a recognizable character. I refer to these unrecognizable characters as *artificial characters*. Thus, on each trial, as stimulus images A and A' were presented in alternation, 24 of the 25 characters (the non-targets) were Chinese and did not change. The single target changed in alternation between a real character and an artificial

character.¹ Note that from this point forward, I will use the terms "Chinese character" and "real character" interchangeably.

For all experiments in this study, the stimulus image pairs (A & A') were presented in alternation as follows: The original image (A) (300 ms), then a blank field (100 ms), then the modified version of the original image (A') (300 ms), then a blank field again (100 ms), then the original image (A) again, and so on (Figure 5). This sequence looped continuously until either (1) the participant pressed a response button to indicate that they had detected the changing character; or (2) 60 seconds had elapsed without a response being made.

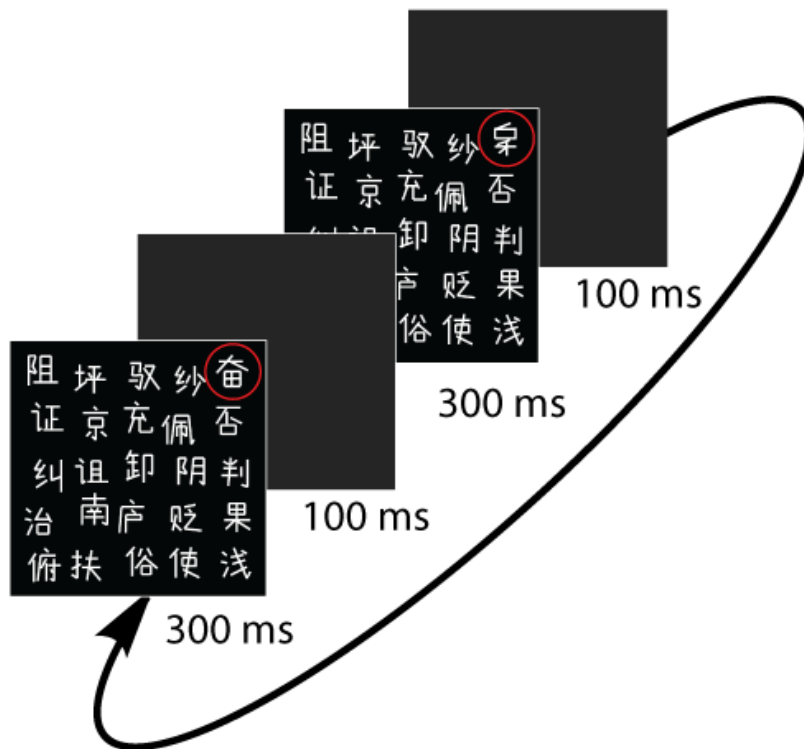


Figure 5. The flicker task display with Chinese characters in current experiments. The target is indicated by red circle (not visible during presentation).

¹ Chinese-artificial target changes were used because they were deemed most suitable for establishing whether or not there would be an effect of reading ability on change detection. But, in future experiments, other types of target changes (e.g., changes between two different Chinese characters) could be used to study questions such as the effect of character meanings on change detection.

Procedure

On each trial, participants saw what appeared to be a single flickering image containing 25 characters and, as quickly as possible, they were asked to find the character that was changing. When they perceived the change, they pressed a response-box button. This stopped the reaction timer and the image flickering. Then the original image was shown and the mouse cursor became visible on the screen. Participants then moved the cursor with the mouse and clicked on the character that they believed was changing. After the mouse click and after a 1-second inter-trial interval, the next trial began. Trials were terminated if participant did not make a change-detection response within 60 seconds. These null responses were recorded as time-out errors. When the participant did respond, but was unable to accurately indicate the changing character's location with the mouse cursor (a rare occurrence), this was recorded as a change-localization error. Participants completed three practice trials while being observed by the experimenter. Over the course of a 30-minute testing session, they completed 75 randomly ordered data trials. These were divided into three blocks of 25 trials with a two-minute break between each block.

Results and Discussion

For each of the experiments in this study, time-out and change-localization error trials were excluded from the analyses. In addition, for each of the experiments, all trials with change-detection response times ± 3 standard deviations away from the corresponding trial-type means were excluded from further analysis as outliers.

Accuracy

Participants in this experiment made very few time-out and change-localization errors. Both readers (98.2%) and non-readers (97.6%) performed the task with high accuracy, no speed-accuracy trade off was observed, and no further inferential analyses were carried out with the response accuracy data.

Response time

Prior to analysis of response times, 3.6% of trials were removed as errors and as response-time outliers for participants in the reader group; and 4.2% of trials were removed for participants in the non-reader group. An independent t-test (one-tailed) was conducted with the mean response times of the two groups of participants to determine whether or not reading ability affected the time required to detect the changing target. The results showed that readers detected the target significantly faster than non-readers ($M = 8748$ ms vs. $M = 12279$ ms respectively), $t_{(50)} = 6.89$, $p < .001$, $d = 1.91$. This suggests that differences in the way readers and non-readers process Chinese characters allowed readers to detect changes to these characters more efficiently. When discussing this finding, I will sometimes refer to this as the *reader advantage*.

Both readers and non-readers could distinguish between two different versions of a target in images A and A' on the basis of visual differences. But only the readers were able to perceive the target in image A as Chinese character, and the target in image A' as a meaningless, orthographically illegal collection of strokes. In other words, only the readers were able to distinguish between the two versions of the target in images A and A' on the basis of visual orthography violations. With years of literacy development, readers gain a deep knowledge of Chinese character orthography and sensitivity to violations of this orthography such as incorrect stroke combinations or radical positioning (e.g., Hsiao, Shillcock & Lavidor, 2007; Hsiao, Shillcock & Lee, 2007; Lo, Hue & Tsai, 2007). When targets in this experiment changed from an orthographically correct (Chinese) character in image A to an orthographically incorrect (artificial) character in image A', this orthography violation would not have been noticed by non-readers. Readers, on the other hand, might be quite sensitive to it. And this could be one reason why they detected changes to Chinese characters faster than non-readers.

Experiment 2

The results of Experiment 1 demonstrate that readers were able to detect a changing target within an array of flickering Chinese characters faster than non-readers. This suggests that their reading ability allowed them to process Chinese characters more efficiently, and to more readily notice the difference between a Chinese and an artificial character. This, in turn, might have allowed readers to compare target identities in flicker images A and A' and discover mismatches faster than non-readers. But would this still be the case if all characters were artificial? In particular, would readers still notice a difference between the two target characters in images A and A' faster than non-readers if these characters were visually similar to Chinese, but were meaningless? Experiment 2 was conducted to test this question.

Another goal of Experiment 2 was to examine the effect of change magnitude on detection times; and whether this would vary, depending on whether stimuli were Chinese or artificial characters. In the previous experiment, only a subset of the strokes of target characters was altered (partial change). It has been proposed that readers might process Chinese characters holistically with radicals being perceived as "chunks" rather than as a collection of individual strokes; or perhaps even with whole characters composed of two radicals being perceived as single "chunks" (e.g., Chen & Yeh, 2015; Su & Samuels, 2010; Wong et al., 2012; Wong et al., 2011a, 2011b; Yeh et al., 2003; Zhao et al., 2014). If readers learn to process Chinese characters holistically in a way that non-readers cannot, then perhaps they might also detect holistic changes to targets faster than non-readers. More specifically, readers might detect *Chinese-character changes* faster than non-readers if they involved all of the target's component strokes (whole change) as opposed to only a subset of them (partial change). And this might not be the case with artificial characters which presumably readers would not process holistically. Thus, another aim of the current experiment was to determine whether or not varying the magnitude of target change (partial vs. whole) would interact with reading ability or be independent of it.

Method

Participants

Forty-five SFU undergraduate students were recruited through the Psychology Department Research Participation System and received course credits in exchange for their participation. In addition, nine SFU undergraduate students were recruited through advertisements posted on bulletin boards at various locations around the campus. These students received a \$10 gift card in exchange for their participation. All participants had normal or corrected-to-normal vision, and had no history of seizure. Of the 54 participants, 27 self-reported to be proficient Chinese readers, and 27 self-reported to have minimal or no experience reading Chinese. The ages of participants in the Chinese-reader group ranged from 17 to 25 years ($M = 20.9$, 22 females). The ages of participants in the non-reader group ranged from 16 to 30 years ($M = 21.3$, 16 females).

Stimuli

Like Experiment 1, on each trial, the stimulus display contained 25 different characters. But, on half of trials in this experiment, all characters were Chinese in image A, and all but one character in image A' were Chinese; and on the other half of trials, all characters in image A and A' were artificial. The latter were similar in overall appearance to real characters, but had illegal stroke combinations. Depending on the trial type, characters were randomly drawn from either a pool of 488 Chinese characters, or from a pool of 488 artificial characters (all created with Adobe Illustrator graphics software). Relative to image A, only one of the 25 characters in image A' was changed. The change was either partial (as in Experiment 1) or involved the whole character. When the change was partial, some of the target's component lines in image A remained the same in image A', but 3 to 5 component lines were altered. When the change involved the whole character, all of the character's component lines in image A and image A' were completely different. Thus, on trials with Chinese characters, target change involved continuous alternation between a Chinese character (image A) and a partially or wholly different artificial character (image A'). On trials with artificial characters, target change involved continuous alternation between an artificial character (image A) and another partially or wholly different artificial character (image A').

Design

This experiment had a 2x2x2 mixed design. The two within-subject factors were (1) the type of characters shown on a particular trial (Chinese vs. artificial), and (2) the magnitude of target character change (partial vs. whole). The between-subject factor was the Chinese reading ability of participants. The two groups of participants completed 25 trials for each of the four within-subject conditions.

Procedure

The procedure was the same as that of Experiment 1. Participants completed four practice trials while being observed by the experimenter. And then, over the course of a 60-minute testing session, they completed 100 randomly ordered data trials. These were divided into four blocks of 25 trials with a two-minute break between each block.

Results and Discussion

Accuracy

As was the case in the previous experiment, participants made very few time-out and change-localization errors (see Table 1). No speed-accuracy trade-off occurred, and no further inferential analyses were carried out with the response accuracy data.

Table 1. Mean response accuracy for readers and non-readers in Experiment 2.

	Chinese character		Artificial character	
	partial change	whole change	partial change	whole change
Readers	.981	.992	.966	.997
Non-readers	.979	.994	.973	.989

Response time

Prior to analysis of response times, 2.8% of trials were removed as errors and as response-time outliers for participants in the reader group; and 2.9% of trials were removed for participants in the non-reader group. A 2x2x2 repeated measures ANOVA was conducted with the mean response times for each participant in each condition.

These means are shown in Figure 6. There was a main effect of reading ability. As in Experiment 1, readers found changes faster than non-readers ($F_{(1,52)} = 5.63, p = .021, \eta_p^2 = .098$). There was also a main effect of character type. Chinese-character changes were detected significantly faster than artificial-character changes ($F_{(1,52)} = 11.4, p = .001, \eta_p^2 = .179$). There was also a significant interaction between reading ability and character type ($F_{(1,52)} = 16.4, p < .001, \eta_p^2 = .240$). That is, readers detected changes faster than non-readers, but only when these changes were made to Chinese characters ($t_{(52)} = 3.76, p < .001, d = 1.02$). Readers did not detect changes any faster than non-readers, however, when these changes were made to artificial characters ($t_{(52)} = .634, p = .53, d = 0.17$).

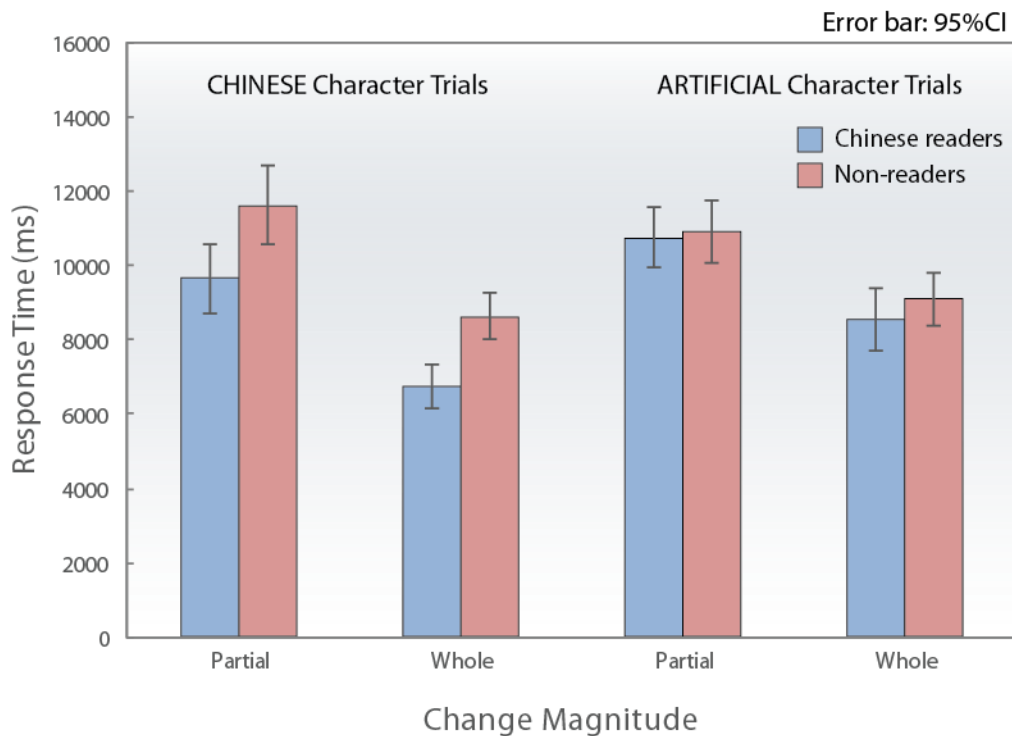


Figure 6. Mean response times for Chinese readers and non-readers in Experiment 2. Error bars denote 95% confidence intervals.

The results of the ANOVA also indicated that whole-character changes were detected faster than partial-character changes ($F_{(1,52)} = 139, p < .001, \eta_p^2 = .727$). There was, however, no significant interaction between reading ability and change magnitude ($F_{(1,52)} = .122, p = .73, \eta_p^2 = .002$). This indicated that, for both groups, finding whole-character changes was easier than finding partial-character changes. There was also a

curious interaction between change magnitude and character type ($F_{(1,52)} = 6.34$, $p = .015$, $\eta_p^2 = .109$).

To examine this more closely, I conducted additional 2x2 repeated measures ANOVAs for each participant group to determine whether or not the same type of interaction between change magnitude and character type held for both readers and non-readers. The analysis of readers' data indicated that they found Chinese-character changes significantly faster than artificial-character changes ($F_{(1,26)} = 43.73$, $p < .001$, $\eta_p^2 = .627$), and they found whole-character changes significantly faster than partial-character changes ($F_{(1,26)} = 87.1$, $p < .001$, $\eta_p^2 = .770$). But, for readers, there was no significant interaction between character type and change magnitude ($F_{(1,26)} = 2.13$, $p = .156$, $\eta_p^2 = .076$). This group required more time to find partial-change targets, regardless of character type. As expected, the analysis of non-readers' data indicated that there was no significant difference between their mean response times for finding changes to Chinese and artificial characters ($F_{(1,26)} = 1.66$, $p = .21$, $\eta_p^2 = .060$). And, like readers, non-readers found whole-character changes significantly faster than partial-character changes ($F_{(1,26)} = 50.78$, $p < .001$, $\eta_p^2 = .661$). Unlike readers, however, there was a Character-Type \times Change-Magnitude interaction for the non-reader group ($F_{(1,26)} = 6.66$, $p = .016$, $\eta_p^2 = .204$). Non-readers took slightly longer to detect partial changes to Chinese characters (unreadable to this participant group) than partial changes to artificial characters ($t_{(26)} = 2.39$, $p = .024$, $d = 0.46$). The reason why is unclear, but it has little bearing on the main findings of this experiment.

As was the case in Experiment 1, when stimuli were Chinese characters, readers were faster than non-readers at detecting changes. But, in this experiment, when stimuli were artificial characters, readers were not faster than non-readers at detecting changes. This might have occurred because when readers compared a Chinese target character in flicker image A with an artificial target character in image A', the mismatch of the characters was quite apparent because the artificial character violated orthographic rules. On the other hand, when readers compared an artificial target character in flicker image A with a different artificial target character in image A', their mismatch was less apparent because both characters violated orthographic rules, and were meaningless to readers. This is further evidence that if the stimuli in this type of experiment are Chinese

characters that participants can read, then they will detect changes faster than when the stimuli are artificial characters that participants cannot read.

Also, as expected, target-change magnitude affected response times. Both readers and non-readers detected whole changes faster than partial changes. This is consistent with previous findings that increasing the size of changing objects leads to faster detection response times (e.g., Smilek et al., 2000; Tovey & Herdman, 2014; Williams & Simons, 2000). With respect to the logographic stimuli in the current experiment, the visual similarity of partial-change target characters in images A and A' was greater than of whole-change target characters. The absence of an interaction between change magnitude and reading ability suggests that the change magnitude effect on response times was due primarily to visual similarity.

Experiment 3

In the previous experiments, it was suggested that readers may have been able to detect mismatches between real characters in image A and artificial characters in image A' primarily on the basis of visual orthography violations. To further examine this possibility, a different type of artificial character called a pseudo character was used in Experiment 3. Pseudo characters are made of legal Chinese radicals, but the characters themselves are meaningless because the pairing of the radicals is incorrect (Chen et al., 1996; Lu, Tang, Zhou & Yu, 2011). Because pseudo characters possess legal orthographic units (radicals) and therefore do not violate orthographic rules to the same extent as other artificial characters, the difference between a real character in image A and a pseudo character in image A' may have less to do with orthographic violation and more to do with their belonging to different lexical categories (meaningful vs. meaningless). If the reader advantage still occurred in Experiment 3, then this might suggest that, with pseudo artificial characters, it is due to a combination of orthographic violation sensitivity and semantic processing.

As mentioned previously, serial search for changes in a flicker display rarely begins at the target location. Instead, observers usually inspect and evaluate several non-targets first. In a large display with 25 items like those in current study, this would almost always be the case. Inspections of non-targets involve comparing identical characters in image A and A', determining that they match (therefore not the target), and then resuming search at another location. And given that most intra-item comparisons involve non-targets, these might also influence search efficiency. In particular, the results of the two previous experiments indicate that there is a reader advantage when target comparisons involve Chinese characters. Is this also the case when *non-target* comparisons involve Chinese characters? That is, when comparing non-target characters in image A and A', will readers detect the match faster with identical Chinese characters than with identical artificial characters? If so, then the nature of non-target items influence response times and must be taken into account when this type of task is performed. In Experiment 3, I examined this possibility by manipulating non-target character types.

Method

Participants

Twenty-eight SFU undergraduate students were recruited through the Psychology Department Research Participation System. They received course credits in exchange for their participation. All participants had normal or corrected-to-normal vision, and had no history of seizure. In addition, all participants self-reported to be proficient Chinese readers. Their ages ranged from 18 to 24 years ($M = 20.5$ years, 19 females).

Stimuli

The Chinese characters in this experiment were the same as those used in previous experiments. The artificial characters, however, were pseudo characters that possessed orthographic units that were visually more familiar to readers than the artificial characters in the previous experiments; but these characters were still artificial because they were meaningless. There were no partial-change targets in this experiment. All trials involved whole character changes between a Chinese character (image A) and an artificial character (image A').

Design

This experiment had a 1x3 within-subject design. On one-third of trials, all 24 non-targets in image A and A' were Chinese characters; on another third of trials, all 24 non-targets were artificial characters. And on another third of trials, the non-target item set was a mix of 12 Chinese and 12 artificial characters. Participants completed 48 trials for each of the three non-target conditions.

Procedure

The procedure was the same as that of the previous experiments. Participants completed four practice trials while being observed by the experimenter. And then, over the course of a 60-minute testing session, they completed 144 randomly ordered data trials. These data trials were divided into six blocks of 24 trials with a two-minute break between each block.

Results and Discussion

Accuracy

Participants made very few time-out and change-localization errors. When the non-target item set was composed entirely of Chinese characters, the mean accuracy of responses was 98.3%. When the non-target item set was composed entirely of artificial characters, the mean accuracy of responses was 97.5%. And when the non-target item set was a heterogeneous mix of 12 Chinese and 12 artificial characters, the mean accuracy of responses was 98.5%. No speed-accuracy trade-off occurred, and no further inferential analyses were carried out with the response accuracy data.

Response time

Prior to analysis of response times, 3.7% of trials were removed as errors and as response-time outliers. A 1x3 repeated-measures ANOVA was conducted with the mean response times for each participant in each condition. These means are shown in Figure 7. The results indicate that the type of character that the non-target item set was composed of had a significant effect on the target detection times ($F_{(1,54)} = 9.24$, $p < .001$, $\eta_p^2 = .255$). As indicated by a post hoc test with Bonferroni correction, when all non-targets were real Chinese characters, participants found targets significantly faster than when all non-targets were artificial characters ($M = 7741$ ms & $M = 8893$ ms respectively) ($p = .002$). The mean response times for finding the target among a heterogeneous mix of (12 Chinese & 12 artificial character) non-targets ($M = 8317$ ms) was neither significantly faster nor slower than the mean response times for the all-Chinese or the all-artificial non-target conditions ($p = .074$ & $p = .089$ respectively). The results of this experiment indicate that targets were detected significantly faster when surrounded by Chinese-character non-targets than when surrounded by artificial-character non-targets. That is, during the course of the serial search, Chinese-character non-targets were inspected and rejected as possible targets faster and more efficiently than artificial character non-targets.

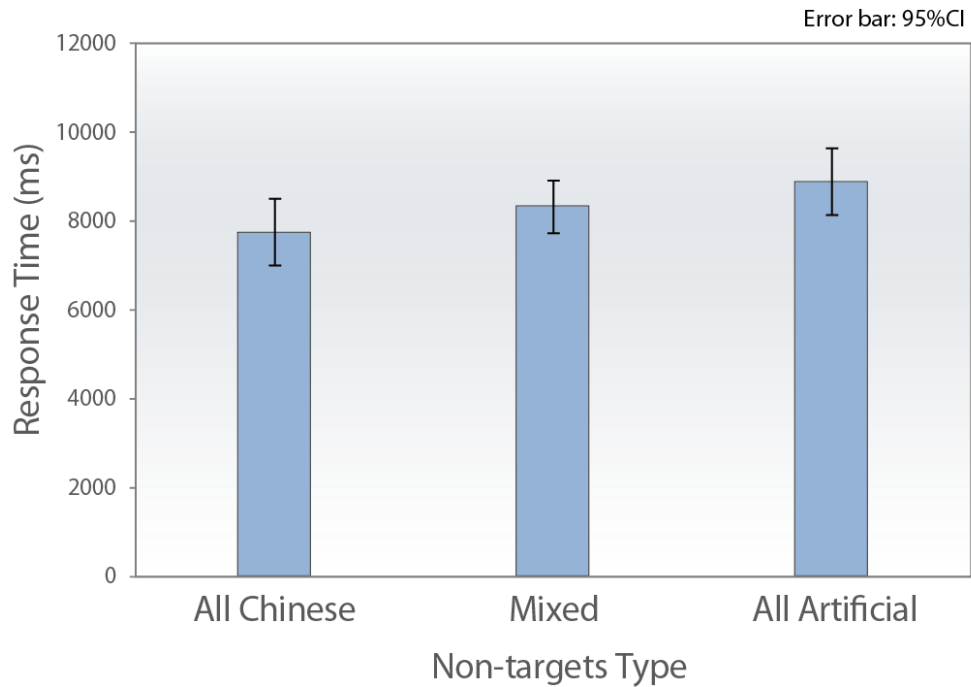


Figure 7. Chinese readers' mean response times in Experiment 3. Error bars denote 95% confidence intervals.

These findings indicate that the nature of non-target items does influence change detection. Inspections of non-target characters involved comparisons of identical characters in image A and A'. And participants detected matches between real characters that they had lexical knowledge of faster than matches between artificial characters that they did not have lexical knowledge of.

General Discussion

The research described in this thesis was conducted to determine whether or not reading ability would facilitate the detection of changes to Chinese characters. The results showed that readers detected changes faster than non-readers if these changes involved Chinese characters, but not if they involved only artificial characters. Furthermore, when the unchanging non-target items in the search array were Chinese characters, readers were able to detect target changes faster than when the non-target items were artificial characters. These findings indicate that reading experience allows readers to detect changes to recognizable, meaningful logographic characters more efficiently than changes to unrecognizable, meaningless artificial characters.

Reader Advantage and Intra-Item Comparison

Flicker-task target detection occurs when characters at the same locations within images A and A' are compared and found to be a mismatch. And flicker-task performance is influenced by the efficiency with which display items can be processed and compared. The more apparent the difference is when characters are compared, the faster the change will be detected. Non-readers in this study determined mismatches between the visual features (i.e., number & positions of strokes) of target characters in image A and A'. Readers could determine target mismatches on the basis of visual differences. But they could also recognize Chinese characters and differentiate them from artificial characters because the latter violated Chinese orthographic rules. Consequently, when making intra-item comparisons between image A and A', the contrast between a Chinese and an artificial character would be more apparent to readers than to non-reader.

Orthography is one of the first types of knowledge acquired when one is learning to read a new language (Luo et al., 2011). Even at the grade three level, young children learning to read Chinese are able to discriminate between orthographically legal and illegal characters (Peng et al., 1997; Shu & Anderson, 1999). Moreover, Chinese readers are able to reject artificial characters faster and more accurately when they are clearly orthographically illegal (e.g. those in Experiment 1 & 2) than when they are closer to being orthographically legal (pseudo characters) (Peng et al., 1997). The skilled

readers who participated in the current study, therefore, would have no difficulty noticing the orthographic violations of artificial characters in Experiments 1 and 2. This might be one reason why they were able to detect mismatches between Chinese and artificial target characters in images A and A' faster than non-readers.

The idea that readers are more sensitive to orthographic configurations of Chinese characters than non-readers is also supported by neurophysiological evidence. Some researchers found that the amplitude of the N170 ERP component (thought to be an index for visual word & orthographic processing) is greater when viewing real characters than when viewing artificial characters with incorrect arrangements of strokes (e.g., Cao & Zhang, 2011; Lin et al., 2011). Other researchers found no increase in amplitude of the N170 component when non-readers viewed Chinese characters (Wei, Dowens & Guo, 2018). In addition, with Chinese readers, visual mismatch negativity (vMMN) was elicited at an early time window (170 - 210 ms) for real-character oddballs (artificial characters as standards). With non-readers, however, there was no evidence of vMMN for either real- or artificial-character oddballs. These findings indicate that readers are able to process the orthographic information in the early stages of Chinese character recognition.

The reader advantage in these experiments might also be associated with holistic processing of well-learned characters. As observers gain perceptual expertise with many types of objects (e.g., faces, fingerprints, English words), visual processing becomes more holistic. And these well-learned objects have been referred to as chunks (Chase & Simon, 1973; Rensink, 2000b, p. 1477). To novices, objects are represented in terms of their parts; whereas, to experts, objects are represented as relatively undifferentiated wholes (e.g., Bukach, Bub, Gauthier & Tarr, 2006; Palmeri & Gauthier, 2004). And during the acquisition of this perceptual expertise, there is a gradual switch from part-based representations to holistic representations. The same appears to be true of Chinese character processing. The results of several studies indicate that skilled readers initially encode Chinese characters as meaningful wholes, as opposed to individual parts that are combined into wholes at a later stage of processing (e.g., Chua, 1999; Liu & Perfetti, 2003; Mo, Yu, Seger & Mo, 2015). But when children begin to learn how to read Chinese, they tend to focus on strokes and radicals. And it is only with practice and more developed reading skill that they process characters more holistically (e.g., Anderson et al., 2013; Pak et al., 2005; Su & Samuels, 2010;).

The results of previous research indicate that holistic processing occurs to a greater degree with real characters than with artificial characters (Chen, Bukach, & Wong, 2013; Wong et al., 2011a, 2011b, 2012). And this also might have contributed to the reader advantage in the current study. More specifically, when readers inspected targets in Experiments 1 and 2, they compared a holistically perceived real character in image A (a single chunk) with a less holistically perceived artificial character in image A' (a collection of strokes). And the difference between the real character in image A and the artificial character in image A' would be more apparent to readers than to non-readers because the latter would not process either character holistically. In terms of chunking, real ⇔ artificial target character comparisons in Experiment 1 were perceived by readers as chunk ⇔ non-chunk. And the difference between the two would be more apparent to them than to non-readers because the latter perceived the characters as non-chunk₁ ⇔ non-chunk₂. But, in Experiment 2, when comparing an artificial character in image A with a different artificial character in image A', the difference would not be more apparent to readers than to non-readers because, as indicated by previous findings, neither would be able to process the artificial characters holistically. Thus, artificial ⇔ artificial target character comparisons in Experiment 2 would be perceived less holistically by both readers and non-readers as non-chunk₁ ⇔ non-chunk₂, and no reader advantage would occur.

Holistic processing of Chinese characters also might have contributed to the efficiency with which readers inspected non-targets. In Experiment 3, all targets were seen in alternation as a real character in image A and an artificial character in image A'. Therefore, the difference in mean response times in the three conditions is attributable to how readers perceived and rejected different types of non-targets. To elaborate, the non-target characters in image A and A' were always identical. In terms of chunking, readers perceived real ⇔ real non-target character comparisons as chunk ⇔ chunk (holistic match); and perceived artificial ⇔ artificial non-target character comparisons as non-chunk ⇔ non-chunk (parts-based match). Faster matching of identical real characters than matching of identical artificial characters is also consistent with the results of experiments involving same-different tasks with English words/non-words and Chinese/artificial characters (e.g., Barron & Henderson, 1977; Barron & Pittenger, 1974; Besner & Jackson, 1975; Chen et al., 1996; Henderson & Chard, 1976). Thus, slower target detection on trials on which all non-targets were artificial is consistent with

previous findings that artificial characters are processed less holistically than real characters.

Non-targets and “Lexical Odd-Item-out”

The faster target detection on trials with all Chinese non-targets than with all artificial non-targets in Experiment 3 raises a question about the interpretation of the results of the first two experiments. To what extent was the reader advantage due to the nature of the targets as opposed to the non-targets? In particular, all non-targets in Experiment 1 were Chinese characters. Given that readers are able to inspect and reject Chinese non-targets faster than artificial non-targets, could this be why they performed the Experiment 1 task more efficiently than non-readers (who cannot inspect and reject Chinese non-targets any faster than they can artificial non-targets)? If so, then perhaps the reader advantage found in Experiments 1 and 2 may be due, in part, to readers being able to inspect and reject the non-targets faster than non-readers. But the relative contributions of Chinese target and Chinese non-target intra-item comparisons to the reader advantage cannot be determined on the basis of the current experiments, and future research is required to address this question. For example, one experiment that might reveal more about potential influence of non-targets on the reader advantage could be a replication of Experiment 1; but could have two types of heterogeneous non-target sets. One set could have 8 Chinese-character non-targets and 16 artificial-character non-targets. The other could have 16 Chinese-character non-targets and 8 artificial-character non-targets. If the magnitude of the reader advantage is unaffected by the type of non-target set, then this would suggest that non-targets do not influence it. On the other hand, if the reader advantage is greater when there are more Chinese-character non-targets, then this would suggest that they account for at least some of this effect. Regardless of whether the reader advantage is due to target comparisons or non-target comparisons, the main finding still holds: reading experience facilitates Chinese character change detection.

Another question raised in Experiment 3 is whether or not a lexical odd-item-out target can influence search efficiency. An odd-item-out target with a unique visual feature (e.g., colour, shape, abrupt-onset) can capture attention and cause visual search to be initiated at its location (e.g., Hickey, McDonald & Theeuwes, 2006; Yantis & Jonides, 1996). In the current experiments, a "lexical" odd-item-out target could be the

only Chinese character in the display, or the only artificial character in the display. Could this lexical odd-item-out also cause visual search to be initiated at its location? The results of Experiment 3 indicate that this is not likely. In particular, targets were not detected significantly faster when they were a lexical odd-item-out than they were not (i.e., surrounded by a heterogeneous set of Chinese and artificial non-targets).

Unlike a typical odd-item-out target that possesses a unique visual feature, determining that a target is a "lexical" odd-item-out requires that an eye movement first be made to its location so that it can be processed for recognition. To elaborate, a number of experiments on eye movements and reading have demonstrated that when English words lie outside the parafoveal field of view (10°), lexical processing is quite limited (Balota & Rayner, 1991; Blanchard, Pollatsek & Rayner, 1989; Bouma, 1978). This parafoveal region of effective vision for reading is called the perceptual span, and it is even smaller when reading Chinese characters (e.g., Chen & Tang, 1998; Inhoff & Liu, 1997, 1998; Liu, Inhoff, Ye & Wu, 2002; Yen, Tsai, Tzeng & Hung, 2008). Given their visual complexity, determining the lexical category of Chinese and artificial characters lying outside the perceptual span would be difficult. In the current study, the spatial extent of the perceptual span for reading Chinese characters was less than 15% of the area of the stimulus displays ($27.6 \times 27.6^\circ$). Therefore, on most trials in these experiments, there is a high probability that lexical odd-item-out targets would not initially lie within the perceptual span; and that several eye movements would be made before such a target was parafoveated and its lexical category could be determined (Figure 8). The current study does not, however, conclusively rule out that possibility that lexical guidance of attention could occur with small displays of characters (e.g., $5 \times 5^\circ$) that can be read with a minimal number of eye movements. And linguistic stimuli like Chinese characters are ideal for testing this question.



Figure 8. Characters cannot be recognized if they are outside the perceptual span (region of effective vision for reading).

Implications

The unique combination of logographic stimuli and the change-detection task in this study allowed me to systematically examine search serial within flickering displays, the factors that influence intra-item comparisons, and how properties of non-target objects affect search efficiency. This would not be feasible with pictorial stimuli that are often used with flicker tasks because the size, shape, and colour of objects within pictorial scenes usually vary to a great degree. Chinese characters, on the other hand, are ideal for studying these questions. And, more generally, their use with the flicker task is a new way to study the role of attention when reading. This is the first study, to my knowledge, that has been conducted with Chinese characters to examine the effect of reading ability on change detection. And the results raise many questions for future research. One of these, for example, is how semantic properties of Chinese characters (e.g., character frequency, familiarity, changes between synonyms or antonyms, etc.) affect change detection. Future work of this type has the potential to provide a bridge between the attention and reading literatures. And it is a novel approach for studying the lexical processes associated with reading.

References

- Anderson, R. C., Ku, Y.-M., Li, W., Chen, X., Wu, X., & Shu, H. (2013). Learning to see the patterns in Chinese characters. *Scientific Studies of Reading, 17*(1), 41-56. <https://doi.org/10.1080/10888438.2012.689789>
- Balota, D. A., & Rayner, K. (1991). Word recognition processes in foveal and parafoveal vision: The range of influence of lexical variables. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp.198-232). Hillsdale, NJ: Erlbaum.
- Barron, R. W., & Henderson, L. (1977). The effects of lexical information on same-different visual comparison of words. *Memory & Cognition, 5*(5), 566-579. <https://doi.org/10.3758/BF03197402>
- Barron, R. W., & Pittenger, J. B. (1974). The effect of orthographic structure and lexical meaning on "same-different" judgments. *Quarterly Journal of Experimental Psychology, 26*(4), 566-581. <https://doi.org/10.1080/14640747408400449>
- Besner, D., & Jackson, A. (1975). Same-different judgments with words and nonwords: A word superiority/inferiority effect. *Bulletin of the Psychonomic Society, 6*(6), 578-580. <https://doi.org/10.3758/BF03337571>
- Björnström, L. E., Hills, C., Hanif, H., & Barton, J. J. (2014). Visual word expertise: A study of inversion and the word-length effect, with perceptual transforms. *Perception, 43*(5), 438-450. <https://doi.org/10.1068/p7698>
- Blanchard, H. E., Pollatsek, A., & Rayner, K. (1989). The acquisition of parafoveal word information in reading. *Perception & Psychophysics, 46*(1), 85-94. <https://doi.org/10.3758/BF03208078>
- Bouma, H. (1978). Visual search and reading: Eye movements and functional field of view: A tutorial review. In J. Requin (Ed.), *Attention & Performance* (Vol. 7, pp.115-143). Hillsdale, NJ: Erlbaum.
- Bridgeman, B., Hendry, D., & Stark, L. (1975). Failure to detect displacement of the visual world during saccadic eye movements. *Vision Research, 15*(6), 719-722. [https://dx.doi.org/10.1016/0042-6989\(75\)90290-4](https://dx.doi.org/10.1016/0042-6989(75)90290-4)
- Bukach, C. M., Bub, D. N., Gauthier, I., & Tarr, M. J. (2006). Perceptual expertise effects are not all or none: Local perceptual expertise for faces in a case of prosopagnosia. *Journal of Cognitive Neuroscience, 18*(1), 48-63. <https://doi.org/10.1162/089892906775250094>
- Buttle, H., & Raymond, J. E. (2003). High familiarity enhances visual change detection for face stimuli. *Perception & Psychophysics, 65*(8), 1296-1306. <https://doi.org/10.3758/BF03194853>

- Cao, X.-H., & Zhang, H.-T. (2011). Change in subtle N170 specialization in response to Chinese characters and pseudocharacters. *Perceptual & Motor Skills*, 113(2), 365-376. <https://doi.org/10.2466/04.22.24.28.PMS.113.5.365-376>
- Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology*, 4(1), 55-81. [http://dx.doi.org/10.1016/0010-0285\(73\)90004-2](http://dx.doi.org/10.1016/0010-0285(73)90004-2)
- Chen, H.-C., & Tang, C.-K. (1998). The effective visual field in Chinese. *Reading & Writing*, 10(3-5), 245-254. <https://doi.org/10.1023/A:1008043900392>
- Chen, H., Bukach, C. M., & Wong, A. C.-N. (2013). Early electrophysiological basis of experience-associated holistic processing of Chinese characters. *PloS ONE*, 8(4): e61221, 1-10. <https://doi.org/10.1371/journal.pone.0061221>
- Chen, Y. P., Allport, D. A., & Marshall, J. C. (1996). What are the functional orthographic units in Chinese word recognition: The stroke or the stroke pattern? *Quarterly Journal of Experimental Psychology*, 49(4), 1024-1043. <https://doi.org/10.1080/713755668>
- Chen, Y.-C., & Yeh, S.-L. (2015). Binding radicals in Chinese character recognition: Evidence from repetition blindness. *Journal of Memory & Language*, 78, 47-63. <https://doi.org/10.1016/j.jml.2014.10.002>
- Chua, F. K. (1999). Visual perception of the Chinese character: Configural or separable processing? *Psychologia*, 42(4), 209-221.
- Clark, K., Fleck, M. S., & Mitroff, S. R. (2011). Enhanced change detection performance reveals improved strategy use in avid action video game players. *Acta Psychologica*, 136(1), 67-72. <https://doi.org/10.1016/j.actpsy.2010.10.003>
- Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, 96(3), 433-458. <https://dx.doi.org/10.1037/0033-295X.96.3.433>
- Goonetilleke, R. S., Lau, W. C., & Shih, H. M. (2002). Visual search strategies and eye movements when searching Chinese character screens. *International Journal of Human-Computer Studies*, 57(6), 447-468. <https://doi.org/10.1006/ijhc.2002.1027>
- Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In K. Akins (Ed.), *Perception* (pp. 89-110). New York, NY: Oxford University Press.
- Henderson, L., & Chard, J. (1976). On the nature of the facilitation of visual comparisons by lexical membership. *Bulletin of the Psychonomic Society*, 7(5), 432-434. <https://doi.org/10.3758/BF03337238>
- Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience*, 18(4), 604-613. <https://doi.org/10.1162/jocn.2006.18.4.604>

- Ho, C. S-H., Yau, P. W-Y., & Au, A. (2003). Development of orthographic knowledge and its relationship with reading and spelling among Chinese kindergarten and primary school children. In C. McBride-Chang & H.-C. Chen (Eds.), *Reading development in Chinese children* (pp. 51– 71). Westport, CT: Praeger Press.
- Hsiao, J. H.-W., Shillcock, R., & Lavidor, M. (2007). An examination of semantic radical combinability effects with lateralized cues in Chinese character recognition. *Perception & Psychophysics*, *69*(3), 338-344. <https://doi.org/10.3758/BF03193754>
- Hsiao, J. H.-W., Shillcock, R., & Lee, C.-Y. (2007). Neural correlates of foveal splitting in reading: Evidence from an ERP study of Chinese character recognition. *Neuropsychologia*, *45*(6), 1280-1292. <https://doi.org/10.1016/j.neuropsychologia.2006.10.001>
- Inhoff, A. W., & Liu, W. (1997). The perceptual span during the reading of Chinese text. In H.-C. Chen (Ed.), *Cognitive processing of Chinese and related Asian languages* (pp. 243-266). Hong Kong: Chinese University of Hong Kong Press.
- Inhoff, A. W., & Liu, W. (1998). The perceptual span and oculomotor activity during the reading of Chinese sentences. *Journal of Experimental Psychology: Human Perception & Performance*, *24*(1), 20-34. <http://dx.doi.org/10.1037/0096-1523.24.1.20>
- Jensen, M. S., Yao, R., Street, W. N., & Simons, D. J. (2011). Change blindness and inattentional blindness. *Wiley Interdisciplinary Reviews: Cognitive Science*, *2*(5), 529-546. <https://doi.org/10.1002/wcs.130>
- Krekelberg, B. (2010). Saccadic suppression. *Current Biology*, *20*(5), R228-R229. <https://dx.doi.org/10.1016/j.cub.2009.12.018>
- Latour, P. (1962). Visual threshold during eye movements. *Vision Research*, *2*(7-8), 261-262. [https://doi.org/10.1016/0042-6989\(62\)90031-7](https://doi.org/10.1016/0042-6989(62)90031-7)
- Lee, C.-Y., Huang, H.-W., Kuo, W.-J., Tsai, J.-L., & Tzeng, J.-L. O. (2010). Cognitive and neural basis of the consistency and lexicality effects in reading Chinese. *Journal of Neurolinguistics*, *23*(1), 10-27. <https://doi.org/10.1016/j.jneuroling.2009.07.003>
- Lin, S. E., Chen, H. C., Zhao, J., Li, S., He, S., & Weng, X. C. (2011). Left-lateralized N170 response to unpronounceable pseudo but not false Chinese characters—the key role of orthography. *Neuroscience*, *190*, 200-206. <https://doi.org/10.1016/j.neuroscience.2011.05.071>
- Liu, H., Jiang, Y., Zhang, B., Ma, L., He, S., & Weng, X. (2013). The orthographic sensitivity to written Chinese in the occipital-temporal cortex. *Experimental Brain Research*, *227*(3), 387-396. <https://doi.org/10.1007/s00221-013-3518-0>

- Liu, W., Inhoff, A. W., Ye, Y., & Wu, C. (2002). Use of parafoveally visible characters during the reading of Chinese sentences. *Journal of Experimental Psychology: Human Perception & Performance*, 28(5), 1213-1227. <https://doi.org/10.1037//0096-1523.28.5.1213>
- Liu, Y., & Perfetti, C. A. (2003). The time course of brain activity in reading English and Chinese: An ERP study of Chinese bilinguals. *Human Brain Mapping*, 18(3), 167-175. <https://doi.org/10.1002/hbm.10090>
- Lo, M., Hue, C.-W., & Tsai, F.-Z. (2007). Chinese readers' knowledge of how Chinese orthography represents phonology. *Chinese Journal of Psychology*, 49(4), 315-334. <https://doi.org/10.6129/CJP.2007.4904.01>
- Lu, Q., Tang, Y.-Y., Zhou, L., & Yu, Q. (2011). The different time courses of reading different levels of Chinese characters: An ERP study. *Neuroscience Letters*, 498(3), 194-198. <https://doi.org/10.1016/j.neulet.2011.03.061>
- Luo, C., Chen, W., & Zhang, Y. (2017). The inversion effect for Chinese characters is modulated by radical organization. *Journal of Psycholinguistic Research*, 46(3), 791-803. <https://doi.org/10.1007/s10936-017-9484-0>
- Luo, Y. C., Chen, X., Deacon, S. H., & Li, H. (2011). Development of Chinese orthographic processing: A cross-cultural perspective. *Writing Systems Research*, 3(1), 69-86. <https://doi.org/10.1093/wsr/wsr008>
- Mack, A., & Rock, I. (1998a). Inattention blindness: Perception without attention. In R.D. Wright (Ed.), *Visual attention* (pp. 55-76). New York, NY: Oxford University Press.
- Mack, A., & Rock, I. (1998b). *Inattention blindness*. Cambridge, MA: MIT Press.
- Matin, E. (1974). Saccadic suppression: A review and an analysis. *Psychological Bulletin*, 81(12), 899-917. <https://dx.doi.org/10.1037/h0037368>
- McBride, C. A. (2016). Is Chinese special? Four aspects of Chinese literacy acquisition that might distinguish learning Chinese from learning alphabetic orthographies. *Educational Psychology Review*, 28(3), 523-549. <https://doi.org/10.1007/s10648-015-9318-2>
- McCandliss, B. D., Cohen, L., & Dehaene, S. (2003). The visual word form area: Expertise for reading in the fusiform gyrus. *Trends in Cognitive Sciences*, 7(7), 293-299. [https://doi.org/10.1016/S1364-6613\(03\)00134-7](https://doi.org/10.1016/S1364-6613(03)00134-7)
- McConkie, G. W., & Zola, D. (1979). Is visual information integrated across successive fixations in reading? *Perception & Psychophysics*, 25(3), 221-224. <https://doi.org/10.3758/BF03202990>

- Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, *90*(2), 227-234. <http://dx.doi.org/10.1037/h0031564>
- Mo, C., Yu, M., Seger, C., & Mo, L. (2015). Holistic neural coding of Chinese character forms in bilateral ventral visual system. *Brain & Language*, *141*, 28-34. <https://doi.org/10.1016/j.bandl.2014.11.008>
- Neisser, U., & Becklen, R. (1975). Selective looking: Attending to visually specified events. *Cognitive Psychology*, *7*(4), 480-494. [https://doi.org/10.1016/0010-0285\(75\)90019-5](https://doi.org/10.1016/0010-0285(75)90019-5)
- O'Regan, J. K., Deubel, H., Clark, J. J., & Rensink, R. A. (2000). Picture changes during blinks: Looking without seeing and seeing without looking. *Visual Cognition*, *7*(1-3), 191-211. <https://doi.org/10.1080/135062800394766>
- O'Regan, J. K., Rensink, R. A., & Clark, J. J. (1999). Change-blindness as a result of "mudsplashes". *Nature*, *398*, 34. <https://doi.org/10.1038/17953>
- Pak, A. K., Cheng-Lai, A., Tso, I. F., Shu, H., Li, W., & Anderson, R. C. (2005). Visual chunking skills of Hong Kong children. *Reading & Writing*, *18*(5), 437-454. <https://doi.org/10.1007/s11145-005-6575-3>
- Palmeri, T. J., & Gauthier, I. (2004). Visual object understanding. *Nature Reviews Neuroscience*, *5*, 291-302. <https://doi.org/10.1038/nrn1364>
- Peng, D.-L., Li, Y.-P., & Yang, H. (1997). Orthographic processing in the identification of Chinese characters. In H.-C. Chen (Ed.), *Cognitive processing of Chinese and related Asian languages* (pp. 85-108). Hong Kong: The Chinese University Press.
- Rensink, R. A. (2000a). Visual search for change: A probe into the nature of attentional processing. *Visual Cognition*, *7*(1-3), 345-376. <https://doi.org/10.1080/135062800394847>
- Rensink, R. A. (2000b). Seeing, sensing, and scrutinizing. *Vision Research*, *40*(10-12), 1469-1487. [https://doi.org/10.1016/S0042-6989\(00\)00003-1](https://doi.org/10.1016/S0042-6989(00)00003-1)
- Rensink, R. A. (2002). Change detection. *Annual Review of Psychology*, *53*, 245-277. <https://doi.org/10.1146/annurev.psych.53.100901.135125>
- Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, *8*(5), 368-373. <https://doi.org/10.1111/j.1467-9280.1997.tb00427.x>
- Richards, J., Platt, J., Weber, H. (1985). *Longman dictionary of applied linguistics*. Harlow, England: Longman.

- Scholl, B. J. (2000). Attenuated change blindness for exogenously attended items in a flicker paradigm. *Visual Cognition*, 7(1-3), 377-396. <https://doi.org/10.1080/135062800394856>
- Sheridan, H., & Reingold, E. M. (2014). Expert versus novice differences in the detection of relevant information during a chess game: Evidence from eye movements. *Frontiers in Psychology*, 5:941, 1-6. <https://doi.org/10.3389/fpsyg.2014.00941>
- Shi, Q., & Wright, R. D., (2016, November). *Color changes affect visual search in a flicker task*. Poster presented at the 57th annual meeting of Psychonomic Society, Boston, MA.
- Shu, H., & Anderson, R. C. (1999). Learning to read Chinese: The development of metalinguistic awareness. In J. Wang, A.W. Inhoff, & H.-C. Chen (Eds.), *Reading Chinese script: A cognitive analysis* (pp. 1-18). Mahwah, NJ: Lawrence Erlbaum.
- Simons, D. J., & Levin, D. (2003). What makes change blindness interesting? In D.E. Irwin & B.H. Ross (Eds.), *The psychology of learning and motivation* (Vol. 42, pp. 295-322). San Diego, CA: Academic Press. [https://doi.org/10.1016/S0079-7421\(03\)01009-0](https://doi.org/10.1016/S0079-7421(03)01009-0)
- Simons, D. J. (2000). Current approaches to change blindness. *Visual Cognition*, 7(1-3), 1-15. <https://doi.org/10.1080/135062800394658>
- Simons, D. J., & Rensink, R. A. (2005). Change blindness: Past, present, and future. *Trends in Cognitive Sciences*, 9(1), 16-20. <https://doi.org/10.1016/j.tics.2004.11.006>
- Smilek, D., Eastwood, J. D., & Merikle, P. (2000). Does unattended information facilitate change detection? *Journal of Experimental Psychology: Human Perception & Performance*, 26(2), 480-487. <http://dx.doi.org/10.1037/0096-1523.26.2.480>
- Su, Y.-F., & Samuels, S. J. (2010). Developmental changes in character-complexity and word-length effects when reading Chinese script. *Reading & Writing*, 23(9), 1085-1108. <https://doi.org/10.1007/s11145-009-9197-3>
- Sun, Y., Yang, Y., Desroches, A. S., Liu, L., & Peng, D. (2011). The role of the ventral and dorsal pathways in reading Chinese characters and English words. *Brain & Language*, 119(2), 80-88. <https://doi.org/10.1016/j.bandl.2011.03.012>
- Tang, C. K., Au Yeung, L. H., & Chen, H.-C. (1997). The effective visual field in the reading of Chinese text. In H.-C. Chen (Ed.), *Cognitive processing of Chinese and related Asian languages* (pp. 267-286). Hong Kong: The Chinese University Press.
- Tovey, M., & Herdman, C. M. (2014). Seeing changes: How familiarity alters our perception of change. *Visual Cognition*, 22(2), 214-238. <https://doi.org/10.1080/13506285.2014.894167>

- Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12(1), 97-136. [https://doi.org/10.1016/0010-0285\(80\)90005-5](https://doi.org/10.1016/0010-0285(80)90005-5)
- Tzeng, Y.-L., Hsu, C.-H., Huang, Y.-C., & Lee, C.-Y. (2017). The acquisition of orthographic knowledge: Evidence from the lexicality effects on N400. *Frontiers in Psychology*, 8:433, 1-15. <https://doi.org/10.3389/fpsyg.2017.00433>
- Tzeng, Y.-L., Hsu, C.-H., Lin, W.-H., & Lee, C.-Y. (2018). Impaired orthographic processing in Chinese dyslexic children: Evidence from the lexicality effect on N400. *Scientific Studies of Reading*, 22(1), 85-100. <https://doi.org/10.1080/10888438.2017.1353996>
- Volkman, F., Schick, A., & Riggs, L. (1968). Time course of visual inhibition during voluntary saccades. *Journal of the Optical Society of America*, 58(4), 562-568. <https://doi.org/10.1364/JOSA.58.000562>
- Wang, Y., & McBride, C. (2016). Character reading and word reading in Chinese: Unique correlates for Chinese kindergarteners. *Applied Psycholinguistics*, 37(2), 371-386. <https://doi.org/10.1017/S014271641500003X>
- Watson, T. L., & Krekelberg, B. (2009). The relationship between saccadic suppression and perceptual stability. *Current Biology*, 19(12), 1040-1043. <https://dx.doi.org/10.1016/j.cub.2009.04.052>
- Wei, D., Dowens, M. G., & Guo, T. (2018). Early lexical processing of Chinese words indexed by visual mismatch negativity effects. *Scientific Reports*, 8:1289, 1-11. <https://doi.org/10.1038/s41598-018-19394-y>
- Werner, S., & Thies, B. (2000). Is “change blindness” attenuated by domain-specific expertise? An expert-novices comparison of change detection in football images. *Visual Cognition*, 7(1-3), 163-173. <https://doi.org/10.1080/135062800394748>
- Williams, P., & Simons, D. J. (2000). Detecting changes in novel, complex three-dimensional objects. *Visual Cognition*, 7(1-3), 297-322. <https://doi.org/10.1080/135062800394829>
- Wolfe, J. M. (1998). What can 1 million trials tell us about visual search? *Psychological Science*, 9(1), 33-39. <https://doi.org/10.1111/1467-9280.00006>
- Wolfe, J. M. (2016). Visual search revived: The slopes are not that slippery: A reply to Kristjansson (2015). *i-Perception*, 7(3), 1-6. <http://doi.org/10.1177/2041669516643244>
- Wolfe, J. M., & Horowitz, T. S. (2017). Five factors that guide attention in visual search. *Nature Human Behaviour*, 1:0058, 1-8. <http://doi.org/10.1038/s41562-017-0058>

- Wong, A. C.-N., Bukach, C. M., Hsiao, J., Greenspon, E., Ahern, E., Duan, Y., & Lui, K. F. H. (2012). Holistic processing as a hallmark of perceptual expertise for nonface categories including Chinese characters. *Journal of Vision*, 12(13):7, 1-15. <https://doi.org/10.1167/12.13.7>
- Wong, A. C.-N., Bukach, C. M., Yuen, C., Yang, L., Leung, S., & Greenspon, E. (2011b). Holistic processing of words modulated by reading experience. *PLoS ONE*, 6(6): e20753, 1-7. <https://doi.org/10.1371/journal.pone.0020753>
- Wong, A. C.-N., Bukach, C. M., Yuen, W. S., Yang, L., Leung, S., & Greenspon, E. (2011a). Holistic processing of Chinese characters. *i-Perception*, 2(4), 346. <https://doi.org/10.1068/ic346>
- Wright, R. D., & Shi, Q., (2017, November). *Change detection of feature position and global-local processing*. Poster presented at the 58th annual meeting of Psychonomic Society, Vancouver, BC.
- Yantis, S., & Jonides, J. (1996). Attentional capture by abrupt onsets: New perceptual objects or visual masking? *Journal of Experimental Psychology: Human Perception & Performance*, 22(6), 1505-1513. <http://dx.doi.org/10.1037/0096-1523.22.6.1505>
- Yeh, S.-L., Li, J.-L., Takeuchi, T., Sun, V., & Liu, W.-R. (2003). The role of learning experience on the perceptual organization of Chinese characters. *Visual Cognition*, 10(6), 729-764. <https://doi.org/10.1080/13506280344000077>
- Yen, M.-H., Tsai, J.-L., Tzeng, O. J.-I., & Hung, D. L. (2008). Eye movements and parafoveal word processing in reading Chinese. *Memory & Cognition*, 36(5), 1033-1045. <https://doi.org/10.3758/MC.36.5.1033>
- Zhao, J., Qian, Y., Bi, H.-Y. & Coltheart, M. (2014). The visual magnocellular-dorsal dysfunction in Chinese children with developmental dyslexia impedes Chinese character recognition. *Scientific Reports*, 4:7068, 1-7. <https://doi.org/10.1038/srep07068>
- Zuber, B., & Stark, L. (1966). Saccadic suppression: Elevation of visual threshold associated with saccadic eye movements. *Exploratory Neurology*, 16(1), 65-79. [https://dx.doi.org/10.1016/0014-4886\(66\)90087-2](https://dx.doi.org/10.1016/0014-4886(66)90087-2)