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ARTICLE

The perceptual span in traditional Chinese

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Abstract
The present study aimed at examining the perceptual span, the visual field area for information extraction within a single fixation, during the reading of traditional Chinese sentences. Native traditional Chinese readers' eye-movements were recorded as they read sentences that were presented using a gaze-contingent technique, in which legible text was restricted within a window that moved in synchrony with the eyes, while characters outside the window were masked. Comparisons of the window conditions with a baseline condition in which no viewing constraint was applied showed that when the window revealed one previous character and three upcoming characters around the current fixation, reading speed and oculomotor activities reached peak performance. Compared to previous results with simplified Chinese reading, based on a similar set of materials, traditional Chinese exhibits a reduction of the perceptual span. We suggest that the visual complexity of a writing system likely influences the perceptual span during reading.

Keywords: eye-movement; perceptual span; traditional Chinese; reading

1. The perceptual span in traditional Chinese

Reading is an important skill that involves visual decoding of printed text. High-acuity vision required for the processing of orthographic detail is restricted strictly to the most central two degrees of the visual field. However, beyond such a narrow area of *foveal* vision, readers can obtain useful information from words that are projected onto the adjacent retinal areas of parafoveal and peripheral vision. The area of effective visual processing within a single fixation during reading defines the *perceptual span*, and this has been determined with the gaze-contingent moving-window paradigm (McConkie & Rayner, 1975). Based on a reader's current gaze location, a 'window' containing fully visible text is created simultaneously, whereas text outside the window is masked. Importantly, the window moves in synchrony with the eye-gaze. A new window is drawn after each saccade, so that a reader sees new words

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around the new fixation location. The size of the window is manipulated experimentally, and the perceptual span is defined as the smallest window for readers to maintain a normal reading performance, as observed in a baseline condition without viewing constraints.

Investigation of the perceptual span has provided the foundation for influential theories of eye-movement control during reading. Classic studies have shown that the perceptual span of adult English readers, on average, covers 4 letters to the left of the current fixation and at least 14 letters to the right of it (McConkie & Rayner, 1975; Rayner et al., 1982). A closely related term, the letter identification span (i.e., the area from which letters are identifiable; Underwood & McConkie, 1985) is about 8 letters to the right of fixation (see Meixner et al., 2022, for a comparison). The perceptual span typically includes the currently fixated foveal word and the first upcoming parafoveal word (Rayner et al., 2010). Interestingly, the size of the perceptual span is not constant but varies across different individuals. In general, beginning readers, whose reading skills are not developed fully, typically have a reduced perceptual span compared to adults. For instance, in one study, beginning readers of English showed a rightward perceptual span of approximately 11 letters (Rayner, 1986). Such a developmental trend of the perceptual span has also been documented for other Roman alphabetic languages, like Finnish (Häikiö et al., 2009) and German (Meixner et al., 2022). In addition, among readers with matched chronological ages, the perceptual span can increase with reading ability (Veldre & Andrews, 2014). Bilingual readers with higher second-language levels showed larger perceptual spans in their second languages (Whitford & Titone, 2015, 2016). Finally, dyslexic readers, with lower reading performances, often exhibit smaller perceptual spans in reading than do typical individuals. In a case study of a dyslexic adult, Rayner et al. (1989) reported that the person had a smaller perceptual span than typical adults. Yan et al. (2013) found that typically developing children were affected more severely than age-matched dyslexic individuals by deprival of parafoveal information in a reading-like rapid automatized naming (RAN) task, which has been demonstrated to be a good predictor of reading development, arguably because it shares many common oculomotor-related processes with text reading. This result similarly indicates a reduction in the perceptual span for dyslexic readers.

The findings reviewed above clearly suggest that individual differences in reading skill and experience can influence the perceptual span. A question arises as to whether and how readers adapt to visual properties of the language environment and adjust the spatial distribution of visual word processing flexibly. Theoretically, cross-language comparison promotes our understanding about linguistic and visual constraints. Wang et al. (2021) calculated the visual complexities of a number of representative orthographies and hypothesized that they could influence the perceptual span during reading. For visually simple Roman alphabets such as English, as mentioned earlier, the perceptual span consists of 4 previous letters and 14 upcoming letters. In contrast, studies of a fundamentally different writing system, Chinese, have revealed a much narrower perceptual span, extending to only 1 previous character and 3 to 4 upcoming characters, corresponding to about two upcoming words (Inhoff & Liu, 1998; Pan et al., 2017; Xie et al., 2020; Yan et al., 2015). The Chinese writing system is characterized by a number of unique properties such as high writing density and high visual complexity; further details of the relationship of these to the present study will be elaborated on below. The influence of visual complexity on the perceptual span has

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been supported by some additional evidence. For instance, an Arabic-derived writing system, Uyghur, is similar to English with respect to letter visual complexity. The perceptual span in Uyghur has been determined to include 5 previous letters and at least 12 upcoming letters, which resembles the span in English reading closely (Zhou et al., 2021). In contrast, letters in the Indic script–based Tibetan share some common features with Chinese, in that both orthographies involve vertical stacking of radicals to form new characters. As such, the relatively high visual complexity in Tibetan leads to a perceptual span consisting of 3 previous letters and 7 to 8 upcoming letters, which is between the corresponding sizes of spans in English and Chinese (Wang et al., 2021). There is also some supporting evidence from Japanese, a mixture of simple characters (Kana) and complex Chinese characters (Kanji). As a consequence, a slightly larger perceptual span has been reported in Japanese than in Chinese, covering 5 to 7 characters (e.g., Osaka, 1987; Osaka & Oda, 1991). To sum up, the perceptual span is possibly adjusted to accommodate the writing system's graphemic properties. However, existing evidence has been based on comparisons across fundamentally different orthographies. It is possible that other language-specific properties may have determined the perceptual span jointly. If so, the influence of visual complexity on the perceptual span could be established much reliably if reading materials are written in two scripts that only differ visually. From this perspective, the Chinese orthography is well-suited for this research purpose.

There has been an increasing number of studies on eye-movement characteristics in Chinese reading in the past decade. The Chinese writing system is fundamentally different from alphabetic writing systems in many respects and therefore offers critical tests to a number of theories that were developed initially based on the reading of alphabetic orthographies. The basic writing units, Chinese characters, occupy the same horizontal and vertical extents and differ in visual complexity, varying between 1 (e.g., 一 for *one*) and 64 strokes (e.g., 龘 for *talkative*). Chinese words are often short, with the majority made up of one or two characters. Most importantly for the present study, there are two varieties of the written script, namely, traditional Chinese (TC) and simplified Chinese (SC). The so-called character simplification was initiated in mainland China in 1956, in the hope of promoting literacy, and a set of SC characters has been established gradually. In general, the simplified characters are written with fewer strokes (e.g., TC: 禮 and SC: 礼). In contrast, the TC characters are standardized, and based on the Clerical script, an archaic style of Chinese calligraphy was invented over 2000 years ago. Over the centuries, the TC character set has been the standard form of printed Chinese, and it is still used commonly as the official script in Chinese-speaking regions other than mainland China, such as Taiwan, Hong Kong, and Macau.

The first study to investigate the perceptual span in Chinese, employing the gaze-contingent moving-window paradigm, was conducted by Inhoff and Liu (1998) and led to milestone results. With adults, they found that the perceptual span extended 1 character to the left of a fixated character and 3 characters to the right of it, concluding an area of five characters of effective vision. The perceptual span thus extended asymmetrically to the right, the direction of reading, mirroring previous results with English readers. However, the span was quite narrow, arguably due to the high visual complexity in Chinese. Using larger samples of participants and reading materials, Yan et al. (2015) confirmed the critical findings reported by Inhoff and Liu (1998), and further demonstrated that the perceptual span can extend to 4 upcoming

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characters. However, eye-tracking studies so far have tested only the perceptual span in SC. To our knowledge, the only study related to the perceptual span in TC was conducted by Chen and Tang (1998). They measured reaction times during readers' self-spaced reading of individually presented characters and concluded there was an effective visual field of 3 characters, including the currently presented character and two upcoming ones. Obviously, such a self-spaced reading paradigm involves readers' explicit responses and differs from the gaze-contingent moving-window paradigm. To establish the perceptual span in TC, it is important to use the more natural and standard gaze-contingent moving-window paradigm.

To sum up, the present study pursued two inter-related goals. One was to determine the size of the perceptual span for a unique and relatively less-studied writing system, traditional Chinese. The other was to gain further insight into the extent to which graphemic properties influence the perceptual span. Chinese sentences can be written in SC and TC scripts, which differ only in terms of visual complexity. This offers the best opportunity to understand the effect of visual complexity. The literature reviewed above strongly suggests that the perceptual span is likely to be smaller in TC than in SC. The actual size of the TC perceptual span, however, is not able to be predicted based on the existing literature and hence was determined using the experimental manipulation explained below.

2. Method

2.1. Participants

Thirty-two university students (mean age = 21.4 years, *SD* = 2.4 years, 20 females and 12 males) participated in the eye-tracking experiment (excluding two participants who had reading comprehension rates lower than 75%). All participants had normal or corrected-to-normal vision. All of them had grown up and been educated in local schools in Hong Kong where TC was the only Chinese written script taught and used. Therefore, they were native readers of TC and were not familiar with SC. Experimental procedures, in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), were approved by the Human Research Ethics Committee of The Education University of Hong Kong. The participants gave their written informed consent prior to the experiment.

2.2. Material and design

The reading materials, consisting of 148 sentences, were based on a subset of the Beijing Sentence Corpus, which was created originally in SC (Pan et al., 2021; Yan et al., 2010a). Considering the difference between SC and TC and the difference in vocabulary, we modified the BSC for Hong Kong readers in the present study using the following steps. First, all sentences were 'translated' to TC. Second, we replaced 111 words from 82 sentences that were specific to mainland Chinese, using words from Hong Kong vocabulary which were of the same length, and most of which had identical, similar, or related meanings. For instance, words 领导 (leader), 营房 (camp), and 认识 (realize) from the original BSC were replaced by 官員 (official), 帳篷 (tent), and 意識 (realize), respectively. The final sentences were 15 to 25 characters (M = 21.0, SD = 2.5) or 7 to 15 words (M = 11.2, SD = 1.6) in length and comprised 1,666 tokens of 922 words (types).

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We used four experimental conditions to determine the size of the perceptual span in TC, including a *full-line* condition in which viewing of the sentences was unrestricted, and three different *window* conditions, respectively, revealed two, three, or four upcoming characters beyond the currently fixated one (henceforth referred to as R2, R3, and R4). Given that previous studies have demonstrated consistently that viewing one leftward character during Chinese reading yields normal reading performance, in the present study, we provided visibility of one character to the left of the current fixation in all three window conditions. This experiment adopted a within-subject and within-item design, where the same experimental sentences were assigned to different conditions for different participants. The sentences were assigned randomly to the conditions using a Latin-square design and were presented in four condition-blocks, with the order of the blocks randomized across the participants. Before each block started, three warm-up trials were provided to familiarize the participants with the current viewing condition.

2.3. Apparatus

The participants' eye-movements were recorded with an Eyelink 1,000 system running at 1,000 Hz. Each sentence was presented in a single line on a 24-inch ASUS VG248QE monitor (resolution: 1,920 × 1,080 pixels; frame rate: 144 Hz) using the Song font. The participants were seated comfortably, with their heads placed on a chin-and-forehead rest at a distance of 60 cm from the monitor. Each character subtended 0.9 degrees of visual angle. All recordings and calibrations were performed monocularly, based on the participants' right eyes, and viewing was binocular (Figure 1).

降低關稅將對香港經濟產生很多正面的影響。 *	Full-line
鏕鏕鏕鏕鏕對香港經鏕鏕鏕鏕鏕鏕鏕鏕鏕鏕。 *	R2
鏕鏕鏕鏕鏕對香港經濟鏕鏕鏕鏕鏕鏕鏕鏕鏕。 *	R3
鏕鏕鏕鏕鏕對香港經濟產鏕鏕鏕鏕鏕鏕鏕鏕。 *	R4

Figure 1. An example sentence displayed with different viewing conditions, given the current fixation on the character '香' in the sentence (as indicated by the asterisks). Visible (i.e., non-masked) characters are highlighted by using gray background only for the purposed of illustration but not during the experiment. Letters outside of the moving-window were masked by an extremely low-frequency character '鏕', mirroring the letter X in moving-window experiments in alphabetic scripts. The sentence is translated as *Lowering tariffs will have many positive effects on Hong Kong's economy.*

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2.4. Procedure

Before the experiment, the participants' gaze-positions were calibrated with a standard 5-point grid (error < 0.5°). After validation of the calibration accuracy, a fixation-target appeared on the left side of the monitor for a drift check. If the eye-tracker identified a participant's gaze on the fixation-target, that target disappeared and a sentence appeared, with the center of the first character in the sentence presented at the fixation-target position. Otherwise, failure to detect a participant's gaze on the initial fixation-target initiated a re-calibration. The participants were instructed to read the sentences silently for comprehension, then to fixate on a dot in the lower-right corner of the monitor, and finally to press a keyboard button to signal trial completion. Twenty-four sentences were followed by an easy yes–no comprehension question to ensure the participants' engagement with the reading task. On average, they answered 90.5% of the questions correctly (*SD* = 4.7%).

2.5. Data analysis

The data and code for analysis can be accessed at the following link: https://osf.io/wu7a4/?view_only=b43645e260c24c4bac70215133827b35. Fixations were determined with an algorithm for saccade detection (Engbert & Kliegl, 2003). Trials containing missing samples, tracker errors, or participants' blinks or coughs during sentence reading were excluded from the analyses (n = 154, 3.3%). Additionally, we deleted 334 sentences (7.3%) with extremely low numbers of effective observations (i.e., less than four fixated words). Following standard procedures, we removed all first and last words and first- and last-fixated words of each sentence (11,300 words). Target words with first-fixation durations (FFDs; duration of the first fixation on a word, irrespective of the total number of fixations) shorter than 60 ms or longer than 600 ms and gaze durations (GD; the sum of all fixation durations during the first-pass reading of a word) longer than 800 ms were removed (n = 718, 2.9%). Additionally, 326 target words (1.3%) with extremely far launch sites over 6 characters were discarded because they may have been reflecting eye-tracker errors or untypical saccadic behaviors. After the selection, we analyzed 23,815 words (95% of all valid words; largely distributed evenly across the conditions) for the following analyses. The critical results did not depend on the choice of a particular criterion.

To determine the minimum amount of information required for normal reading and oculomotor behaviors, we established a planned treatment contrast to compare each window condition with the baseline full-line condition. Estimates for the effects of viewing constraints were based on linear mixed models for continuous dependent variables, and based on generalized linear mixed models for categorical dependent variables, using the lme4 package (version 1.1–23; Bates et al., 2015) and the lmerTest package (version 3.1–2; Kuznetsova et al., 2017) in the R-language environment (R Development Core Team, 2018). For the random-effects, we included subject- and item-related variance components for intercepts and random-slopes for the fixed-effects and started with full random-effects. Following a standard parsimonious model selection procedure (Matuschek et al., 2017), we dropped correlation parameters and small variance parameters for successful model convergence. Fixation durations were log-transformed prior to statistical analysis to correct positive skewing (Kliegl et al., 2010).

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3. Results

To determine the general effect of viewing limitations, a global performance measure of reading speed, in number of characters per minute, is reported in Table 1, Table 2, and Figure 2A. In contrast to the full-line condition, there was a robust decrease in reading speed due to viewing constraints only for the R2 condition, indicating that the window hampered reading. The other two windowed conditions did not differ reliably from the baseline, suggesting that presenting three upcoming characters provided adequate information for the participants' normal reading in TC.

Table 1. Effects of viewing constraint

Measure	R2	R3	R4	Full line
RS	363 (73)	403 (91)	417 (99)	403 (90)
SP	27.1 (9.0)	35.0 (11.1)	38.0 (10.6)	35.9 (11.5)
FFD	257 (29)	248 (29)	247 (30)	246 (32)
GD	286 (35)	267 (37)	266 (36)	269 (34)
SA	2.31 (0.41)	2.66 (0.52)	2.81 (0.55)	2.73 (0.69)
RP	12.0 (8.8)	8.2 (7.2)	8.2 (6.7)	9.9 (6.4)

Note. Means (and standard deviations in parenthesis) for different measures: reading speed (RS) in characters per minute, skipping probability (SP) in percent, first-fixation duration (FFD) in ms, gaze duration (GD) in ms, interword saccade amplitude (SA) in number of characters, and refixation probability (RP) in percent. Values were computed across participants' means.

Table 2. Overview of model outputs

Fixed-effects	*Est.*	*SE*	*df*	*t/z*	*p*
A. Reading speed					
Full line	403.171	15.357	32.890	26.254	<0.001
R2 versus Full	−40.182	10.651	32.176	−3.773	<0.001
R3 versus Full	0.093	9.156	32.018	0.010	0.601
R4 versus Full	14.208	11.672	31.846	1.217	0.461
B. Gaze duration					
Full line	5.521	0.021	34.583	256.875	<0.001
R2 versus Full	0.068	0.012	35.409	5.937	<0.001
R3 versus Full	0.000	0.010	37.865	0.045	0.964
R4 versus Full	−0.007	0.009	37.081	−0.789	0.435
C. Skipping probability					
Full line	−0.610	0.084		−7.284	<0.001
R2 versus Full	−0.442	0.033		−13.493	<0.001
R3 versus Full	−0.050	0.032		−1.550	0.121
R4 versus Full	0.087	0.032		2.698	<0.001
D. Refixation probability					
Full line	−2.472	0.157		−15.762	<0.001
R2 versus Full	0.228	0.059		3.881	<0.001
R3 versus Full	−0.226	0.065		−3.490	<0.001
R4 versus Full	−0.220	0.066		−3.330	<0.001
E. First-fixation duration					
Full line	5.453	0.021	33.314	259.551	<0.001
R2 versus Full	0.054	0.012	32.419	4.653	<0.001
R3 versus Full	0.015	0.009	33.921	1.675	0.103
R4 versus Full	0.007	0.008	32.484	0.928	0.360
F. Saccade amplitude					
Full line	2.602	0.081	32.104	32.083	<0.001
R2 versus Full	−0.311	0.050	31.518	−6.196	<0.001
R3 versus Full	0.003	0.045	31.555	0.056	0.956
R4 versus Full	0.149	0.050	31.121	2.964	0.006

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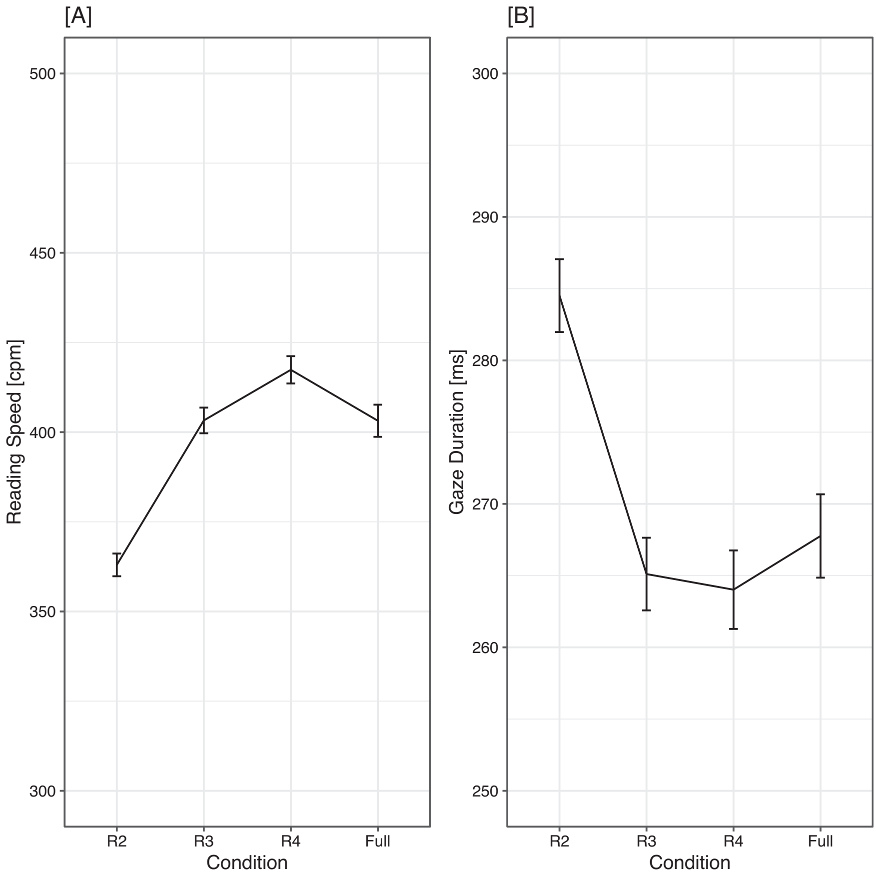

Figure 2. Partial effects (i.e., model estimates after statistical control of between-subject and between-sentence differences) on reading speed (left panel) and gaze duration (right panel) as a function of viewing condition, generated using the remef (version 0.6.10; Hohenstein & Kliegl, 2015) and the ggplot2 packages (version 2.1.0; Wickham, 2009). Error bars indicate twice standard errors of the mean.

We additionally analyzed a number of oculomotor indexes to provide a more fine-grained picture of the viewing constraint effect. Among these indexes, we focused on GD, which is perhaps the most widely reported index in eye-movement research and is particularly sensitive to the cognitive processes of linguistic information for visual word recognition (Inhoff & Radach, 1998; Inhoff & Weger, 2003; Just & Carpenter, 1980). Our analysis showed a converging pattern and echoed that in reading speed, GD significantly increased over the baseline only in the R2 condition, but not in the R3 or R4 conditions, implying that previewing three or more upcoming characters no longer affected reading (Table 2 and Figure 2B).

Other aspects of the readers' oculomotor activity, including skipping probability, saccade amplitude, first-fixation duration, and refixation probability (Tables 1 and 2) are reported below. All oculomotor measures showed reliable effects of viewing constraints in the R2 condition. Previewing two upcoming characters led to less skipping, longer FFD, shorter saccades, and more refixations. In contrast, neither R3

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nor R4 altered the participants' general reading patterns from the baseline, as reflected in fixation duration indexes. However, indexes related to saccade generation appeared in an opposite direction, as predicted by a view that restricting parafoveal information should lower reading performance. The participants made fewer refixations in the windowed conditions than in the baseline condition. Additionally, the participants made longer saccades and skipped more words in the R4 condition than in the baseline condition. Overall, reading and oculomotor indexes converged and jointly indicated that the perceptual span of these skilled TC readers extended from 1 character to the left of fixation to 3 characters to its right.

In a supplemental analysis to demonstrate the difference in the perceptual span between TC and SC, we combined the data from the present study with previously reported data based on 28 SC readers (Yan et al., 2015, Experiment 1). The two datasets were based on nearly identical reading materials. We submitted the entire dataset into 2 (script type) × 4 (viewing constraint) two-way factorial analyses. As expected, significant interactions (R2-Full × Script: $b = -0.301$, $SE = 0.009$, $t = -3.49$, $p < 0.001$ and R3-Full × Script: $b = -0.318$, $SE = 0.009$, $t = -3.52$, $p < 0.001$) statistically confirmed that the perceptual span is smaller in TC than in SC (Figure 3).

4. Discussion

The perceptual span is theoretically important as it provides a foundation for research on eye movements in reading, and theories of eye-movement control are

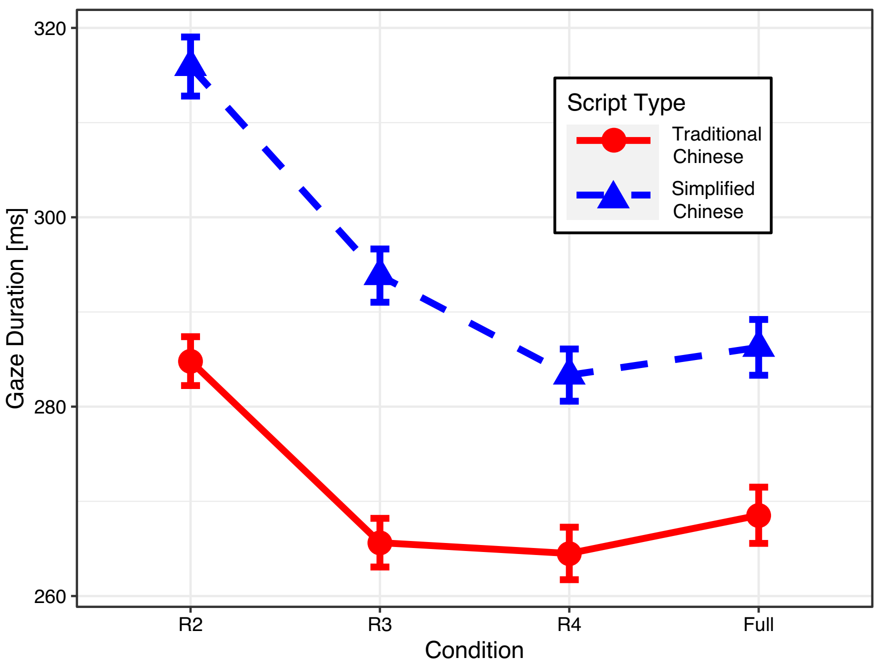

Figure 3. Partial effects on gaze duration of viewing condition and script type (red solid line for traditional Chinese and blue dashed line for simplified Chinese), generated using the remef (version 0.6.10; Hohenstein & Kliegl, 2015) and the ggplot2 packages (version 2.1.0; Wickham, 2009). Error bars indicate twice standard errors of the mean.

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built on assumptions regarding the perceptual span (Engbert et al., 2005; Reichle et al., 1998). Despite its theoretical significance, how the perceptual span is modulated by language-related factors, such as orthographic visual complexity, is still not fully understood. The present study was an attempt to shed light on the use of visual information during reading. For this purpose, we focused on the Chinese language, which has two different varieties of written script that differ only in visual complexity. We utilized the moving-window paradigm to determine, for the first time, the perceptual span in TC. The main results are clear-cut: viewing constraints had a robust influence on the participants' reading performance. Analyses of reading speed and gaze duration showed converging evidence that an increase in the window size approximated peak reading performance as observed in the baseline condition, when 1 character to the left of the currently fixated one and at least 3 characters to the right of it were presented during each fixation. Therefore, we have determined in the current study that the spatial range of information processing covers an area of 5 characters during skillful adult readers' reading of TC sentences.

Previous studies have suggested a possible influence of visual complexity on the size of the perceptual span. Across a number of writing systems that have been explored for the perceptual span, SC has the highest visual complexity and has shown the smallest perceptual span when measured in its basic writing unit (Inhoff & Liu, 1998; Xie et al., 2020; Yan et al., 2015). Importantly, in the present study, our findings indicate that the size of the perceptual span reduces further in TC. Focusing on the special characteristic of Chinese with two varieties of writing script and comparing the current results to previous findings reported by Yan et al. (2015), an influence of orthographic complexity is visible because the reading materials used in the two studies to determine the perceptual spans in SC and TC, respectively, were almost identical, except for the visual complexity. From an experimental control approach, it would be even better to adopt a within-subject design, in which the same participants read sentences written in SC and TC, to rule out possible influences from individual differences. Such a design is unfeasible because Chinese readers are often accustomed to only one of the two written varieties, and finding a sample of participants who are native to both SC and TC is unlikely. Nevertheless, using essentially identical materials and data preprocesses, our supplemental between-experiment comparison between the current dataset and that reported by Yan et al. (2015) has revealed significant interactions of script type and perceptual span, substantiating the claim that the perceptual span is smaller in TC.

So far, most studies of the perceptual span have focused on Roman alphabets. The dynamic modulation of the perceptual span has been demonstrated previously by Inhoff et al. (1989). They presented text either only up to the fixated word or to the first subsequent word, using the gaze-contingent moving-window manipulation. Their results showed that readers extracted more parafoveal information when words were normal than when they were transformed. Similarly, Henderson and Ferreira (1990) adopted a gaze-contingent boundary paradigm where a target word was either parafoveally visible or masked (Rayner, 1975) and demonstrated that parafoveal processing was less efficient when foveal processing was more difficult. They concluded that readers' more effortful foveal processing narrows their perceptual span and reduces parafoveal processing efficiency. Meixner et al. (2022) first showed that foveal load also modulates foveal processing efficiency in the moving-window paradigm.

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Chinese is perhaps the most extensively examined non-Roman script. The landmark study by Inhoff and Liu (1998) has shown a rather narrow perceptual span among SC adults, covering only 3 upcoming characters. More recently, Yan et al. (2015) found that the perceptual span in SC can extend to 4 upcoming characters and that it decreases in size with an increasing font size. Pan et al. (2017) explored the perceptual span in two different reading tasks, reading silently and aloud. They reported a reduced perceptual span in the latter case, where an additional articulatory demand presumably competes with lexical access for processing resources. Focusing on typically developing readers, Yan et al. (2020) reported that the perceptual span of Grade 3 beginning SC readers, on average, included only 2 upcoming characters. However, children with higher reading fluency levels exhibited a larger and more adult-like perceptual span, covering 3 upcoming characters. These studies have suggested that higher processing load, caused by extra articulatory demands when adults' loud reading or children's low visual decoding and word recognition skills, leaves less attentional resource available for parafoveal processing of upcoming words and leads to a smaller perceptual span. There is also evidence from the gaze-contingent boundary paradigm showing that parafoveal processing efficiency is modulated by processing load during the reading of Chinese sentences (e.g., Yan & Sommer, 2019; Yan et al., 2010b; see also Yang et al., 2009, 2012, for a cross-experiment comparison). In the present study, with, on average, more complex visual forms of words, it was likely that more visual decoding processing was required when reading TC sentences than SC sentences. As such, our results are compatible with the view that processing load dynamically modulates the perceptual span in reading, which has been implemented in computational models of eye-movement control during reading (e.g., Schad & Engbert, 2012).

Interestingly, we found some small benefits in saccade-related indexes when restricting the readers' vision. For instance, the participants were less likely to refixate on words in the R3/R4 windowed conditions, and they exerted a longer saccade and skipped words more often in the R4 condition. Similar effects have been reported previously for skilled (Yan et al., 2015) and developing SC readers (Yan et al., 2020). For instance, Yan et al. (2020) reported that children skipped words more often in a R3 windowed condition over the baseline (skipping probabilities: 13.9% versus 11.5%). Yan et al. (2015) proposed that masking characters beyond the first upcoming word may ease parafoveal word segmentation from a string of characters. As well, it has been shown in other languages that readers may rely on information located further for the targeting of saccades (e.g., Apel et al., 2012; Wang et al., 2021). Further work is needed to determine the underlying mechanism of these benefits when window size is near threshold.

Although the gaze-contingent moving-window paradigm has achieved fruitful outcomes in understanding the spatial limit of visual processing in reading, it may fall short in capturing the influence of some detailed factors such as syntactic structure. For instance, semantic isolation in a multi-character window may prevent readers from processing further ahead. This could be a possible limitation of the gaze-contingent moving-window paradigm: the visible window moves with the eye-gaze as self-determined by the readers, which cannot be manipulated in advance. In this sense, it is useful to adopt the gaze-contingent boundary paradigm (Rayner, 1975), where the type and visibility of parafoveal information are under a strict experimental control, to explore effects of syntactic structures. For instance, Yang et al. (2009)

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reported a larger preview effect of a character (thus indicating a larger perceptual span), when it belonged to the first, rather than the second, upcoming word.

5. Conclusion

The present study established the perceptual span during the reading of traditional Chinese sentences and found that, on average, the TC readers relied on an area including one preceding character and three upcoming ones around the currently fixation for reading effectively. Compared to earlier SC results based on a largely identical set of reading materials, the TC readers exhibited a reduced perceptual span, presumably due to an increase in the visual complexity of the writing script. We recommend future studies to explore lifespan development of TC and SC readers' perceptual spans.

Data availability statement. The data and code for analysis can be found at: https://osf.io/wu7a4/?view_only=b43645e260c24c4bac70215133827b35

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Competing interest. The authors declare none.

References

Apel, J. K., Henderson, J. M., & Ferreira, F. (2012). Targeting regressions: Do readers pay attention to the left? *Psychonomic Bulletin & Review*, 19, 1108–1113. https://doi.org/10.3758/s13423-012-0291-1

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Chen, H.-C., & Tang, C. K. (1998). The effective visual field in reading Chinese. In C. K. Leong & K. Tamaoka (Eds.), *Cognitive processing of the Chinese and the Japanese languages* (pp. 91–100). Springer.

Engbert, R., & Kliegl, R. (2003). Microsaccades uncover the orientation of covert attention. *Vision Research*, 43, 1035–1045. https://doi.org/10.1016/S0042-6989(03)00084-1

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review*, 112, 777–813. https://doi.org/10.1037/0033-295X.112.4.777

Häikiö, T., Bertram, R., Hyönä, J., & Niemi, P. (2009). Development of the letter identity span in reading: Evidence from the eye movement moving window paradigm. *Journal of Experimental Child Psychology*, 102, 167–181. https://doi.org/10.1016/j.jecp.2008.04.002

Henderson, J. M., & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 16, 417–442. https://doi.org/10.1037/0278-7393.16.3.417

Inhoff, A. W., & Liu, W. (1998). The perceptual span and oculomotor activity during the reading of Chinese sentences. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 20–34. https://doi.org/10.1037/0096-1523.24.1.20

Inhoff, A. W., Pollatsek, A., Posner, M. I., & Rayner, K. (1989). Covert attention and eye movements during reading. *Quarterly Journal of Experimental Psychology: Section A. Human Experimental Psychology*, 41, 63–89. https://doi.org/10.1080/14640748908402353

Inhoff, A. W., & Radach, R. (1998). Definition and computation of oculomotor measures in the study of cognitive processes. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 29–54). Elsevier.

https://doi.org/10.1017/langcog.2023.24 Published online by Cambridge University Press

Inhoff, A. W., & Weger, U. (2003). Advancing the methodological middle ground. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 335–344). Elsevier Science.

Just, M. A., & Carpenter, P. A. (1980). Inference processes during reading: Reflections from eye fixations. In J. W. Senders, D. F. Fisher, & R. A. Monty (Eds.), *Eye movements and the higher psychological functions* (pp. 157–174). Erlbaum.

Kliegl, R., Masson, M. E. J., & Richter, E. M. (2010). A linear mixed model analysis of masked repetition priming. *Visual Cognition*, 18, 655–681. https://doi.org/10.1080/13506280902986058

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*, 82(13), 1–26. https://doi.org/10.18637/jss.v082.i13

Matuschek, H., Kliegl, R., Vasishth, S., Baayen, H., & Bates, D. (2017). Balancing Type I error and power in linear mixed models. *Journal of Memory and Language*, 94, 305–315. https://doi.org/10.1016/j.jml.2017.01.001

Meixner, J. M., Nixon, J. S., & Laubrock, J. (2022). The perceptual span is dynamically adjusted in response to foveal load by beginning readers. *Journal of Experimental Psychology: General*, 151, 1219–1232. https://doi.org/10.1037/xge0001140

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception & Psychophysics*, 17, 578–586. https://doi.org/10.3758/BF03203972

Osaka, N. (1987). Effect of peripheral visual field size upon eye movements during Japanese text processing. In J. K. O'Regan & A. Levy-Schoen (Eds.), *Eye movements: From physiology to cognition* (pp. 421–429). Elsevier.

Osaka, N., & Oda, K. (1991). Effective visual field size necessary for vertical reading during Japanese text processing. *Bulletin of the Psychonomic Society*, 29, 345–347. https://doi.org/10.3758/BF03333939

Pan, J., Yan, M., & Laubrock, J. (2017). Perceptual span in oral reading: The case of Chinese. *Scientific Studies of Reading*, 21, 254–263. https://doi.org/10.1080/10888438.2017.1283694

Pan, J., Yan, M., Richter, E. M., Shu, H., & Kliegl, R. (2022). The Beijing sentence corpus: A Chinese sentence corpus with eye movement data and predictability norms. *Behavior Research Methods*, 54, 1989–2000. https://doi.org/10.3758/s13428-021-01730-2

R Development Core Team. (2018). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Rayner, K. (1975). The perceptual span and peripheral cues during reading. *Cognitive Psychology*, 7, 65–81. https://doi.org/10.1016/0010-0285(75)90005-5

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *Journal of Experimental Child Psychology*, 41, 211–236. https://doi.org/10.1016/0022-0965(86)90037-8

Rayner, K., Murphy, L., Henderson, J. M., & Pollatsek, A. (1989). Selective attentional dyslexia. *Cognitive Neuropsychology*, 6, 357–378. https://doi.org/10.1080/02643298908253288

Rayner, K., Slattery, T., & Bélanger, N. N. (2010). Eye movements, the perceptual span, and reading speed. *Psychonomic Bulletin & Review*, 17, 834–839. https://doi.org/10.3758/PBR.17.6.834

Rayner, K., Well, A. D., Pollatsek, A., & Bertera, J. H. (1982). The availability of useful information to the right of fixation in reading. *Perception & Psychophysics*, 31, 537–550. https://doi.org/10.3758/BF03204186

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review*, 105, 125–157. https://doi.org/10.1037/0033-295X.105.1.125

Schad, D. J., & Engbert, R. (2012). The zoom lens of attention: Simulating shuffled versus normal text reading using the SWIFT model. *Visual Cognition*, 20(4–5), 391–421. https://doi.org/10.1080/13506285.2012.670143

Underwood, N. R., & McConkie, G. W. (1985). Perceptual span for letter distinctions during reading. *Reading Research Quarterly*, 20, 153–162. https://doi.org/10.2307/747752

Veldre, A., & Andrews, S. (2014). Lexical quality and eye movements: Individual differences in the perceptual span of skilled adult readers. *The Quarterly Journal of Experimental Psychology*, 67(4), 703–727. https://doi.org/10.1080/17470218.2013.826258

Wang, A., Yan, M., Wang, B., Jia, G., & Inhoff, A. W. (2021). The perceptual span in Tibetan reading. *Psychological Research*, 85, 1307–1316. https://doi.org/10.1007/s00426-020-01313-4

Whitford, V., & Titone, D. (2015). Second-language experience modulates eye movements during first- and second-language sentence reading: Evidence from the moving window paradigm. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 41, 1118–1129. https://doi.org/10.1037/xlm0000093

https://doi.org/10.1017/langcog.2023.24 Published online by Cambridge University Press

Whitford, V., & Titone, D. (2016). Eye movements and the perceptual span during first- and second-language sentence reading in bilingual older adults. *Psychology and Aging*, 31, 58–70. https://doi.org/10.1037/a0039971

Wickham, H. (2009). *ggplot2. Elegant graphics for data analysis*. Springer.

Xie, F., McGowan, V. A., Chang, M., Li, L., White, S. J., Paterson, K. B., Wang, J., & Warrington, K. L. (2020). Revealing similarities in the perceptual span of young and older Chinese readers. *Quarterly Journal of Experimental Psychology*, 73, 1189–1205. https://doi.org/10.1177/1747021819899826

Yan, M., Kliegl, R., Richter, E. M., Nuthmann, A., & Shu, H. (2010a). Flexible saccade-target selection in Chinese reading. *Quarterly Journal of Experimental Psychology*, 63, 705–725. https://doi.org/10.1080/17470210903114858

Yan, M., Kliegl, R., Shu, H., Pan, J., & Zhou, X. (2010b). Parafoveal load of word n + 1 modulates preprocessing effectiveness of word n + 2 in Chinese reading. *Journal of Experimental Psychology: Human Perception and Performance*, 36, 1669–1676. https://doi.org/10.1037/a0019329

Yan, M., Li, H., Su, Y., Cao, Y., & Pan, J. (2020). The perceptual span and individual differences among Chinese children. *Scientific Studies of Reading* 24, 520–530. https://doi.org/10.1080/10888438.2020.1713789

Yan, M., Pan, J., Laubrock, J., Kliegl, R., & Shu, H. (2013). Parafoveal processing efficiency in rapid automatized naming: A comparison between normal and dyslexic children. *Journal of Experimental Child Psychology*, 115, 579–589. https://doi.org/10.1016/j.jecp.2013.01.007

Yan, M., & Sommer, W. (2019). The effects of emotional significance of foveal words on the parafoveal processing of n+2 words in reading Chinese sentences. *Reading and Writing*, 32(5), 1243–1256. https://doi.org/10.1007/s11145-018-9914-x

Yan, M., Zhou, W., Shu, H., & Kliegl, R. (2015). Perceptual span depends on font size during the reading of Chinese sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 41, 209–219. https://doi.org/10.1037/a0038097

Yang, J., Rayner, K., Li, N., & Wang, S. (2012). Is preview benefit from word n + 2 a common effect in reading Chinese? Evidence from eye movements. *Reading and Writing*, 25, 1079–1091. https://doi.org/10.1007/s11145-010-9282-7

Yang, J., Wang, S., Xu, Y., & Rayner, K. (2009). Do Chinese readers obtain preview benefit from word n + 2? Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, 35(4), 1192–1204. https://doi.org/10.1037/a0013554

Zhou, W., Wang, A., & Yan, M. (2021). Eye movements and the perceptual span among skilled Uighur readers. *Vision Research*, 182, 20–26. https://doi.org/10.1016/j.visres.2021.01.005

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