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Perceptual span in Mongolian text reading

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Abstract

In this study, an eye-tracking experiment was conducted to investigate the perceptual span during traditional Mongolian reading, a script uniquely written vertically. We adopted a gaze-contingent moving-window paradigm to measure the size of the perceptual span when reading traditional Mongolian sentences. The results showed that the perceptual span was asymmetric downward, extending one syllable above the fixation and three syllables below the fixation. These findings are important for understanding how reading direction affects the underlying cognitive mechanisms during reading and will help to understand the universal mechanisms of reading.

Keywords Mongolian reading · Eye movements · Perceptual span

Eye movement research in reading has provided substantial insights into how we process written text. In the early stages of visual information perception, three areas are distinguished by their visual acuity: the *fovea*, the *parafovea*, and the *periphery* (Rayner & Bertera, 1979). The fovea, with higher visual acuity, covers an area of 1°-2° from the center, compared to the parafovea (extending 2°-5° from the center) and the peripheral area (beyond 5°from the center; Rayner, 1998; Rayner & Bertera, 1979). As written text comprises fine lines and marks, high visual acuity is essential for efficient information extraction. Readers, therefore, engage in rapid and frequent eye movements, known as saccades, to position the fovea over the target words, facilitating effective word identification (Rayner, 1998; Rayner et al., 2016). Between the saccades, moments of fixation occur, where the eyes remain relatively stable for approximately 250ms in skilled adult readers (Rayner, 1984, 1993, 1998). During this period of time, readers can extract and process visual information. However, this does not mean that information can only be obtained through the area of fovea. While the parafovea does not match the fovea's visual acuity, it still plays a role in the extraction of visual information (Rayner & Bertera, 1979; Schotter et al., 2012). The interplay of the fovea and parafovea in visual perception is a fundamental component of reading efficiency (Blanchard et al., 1989). Understanding how readers extract visual information during reading leads to an essential question: What is the extent of the effective field of view?

During reading, the amount of information that readers can efficiently perceive during fixation is usually called *perceptual span*, and the spatial extent of the perceptual span is limited (Rayner, 1998; Rayner et al., 2009). The size of the perceptual span is usually estimated using a gaze-contingent moving window paradigm (McConkie & Rayner, 1975; Rayner & Bertera, 1979). According to the moving window paradigm, readers can see text within a window around the fixation but cannot see text outside this window, because the texts outside the window are replaced by other letters such as Xs. Readers are free to move their eyes whenever and wherever they wish, but the amount of useful information that is available on each fixation is controlled by the experimenter. The key hypothesis of this paradigm is that when the window is as large as the region from which the reader can obtain information, there is no difference between reading in that situation and when there is no window. In general, in English, the size of the perceptual span is 3 to 4 letter spaces to the left of fixation and 14 to 15 letter spaces to the right of fixation (McConkie & Rayner, 1976; Rayner et al., 1980).

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When a word falls within the perceptual span, it is perceivable but not necessarily fully identifiable. Indeed, the word-identification span, which is the area where words can be fully recognized, is significantly smaller than the perceptual span. Specifically, the word-identification span is about 7 characters to the right of fixation in English (McConkie & Zola, 1987; Rayner, 1998; Rayner et al., 1982; Underwood & McConkie, 1985). The perceptual span serves as a larger window to perceive the visual layout of the text (i.e., where is the word boundary) in order to plan the next eye movements.

The characteristics of writing systems significantly influence the size and shape of the perceptual span. In alphabetic languages like English (McConkie & Rayner, 1975) and Dutch (Den Buurman et al., 1981), the perceptual span tends to be more extensive compared to languages that utilize syllabic or morphosyllabic systems (Li et al., 2022), such as Chinese (Inhoff & Liu, 1998; Yan et al., 2015), Japanese (Ikeda & Saida, 1978; Osaka, 1987) and Korean (Choi & Koh, 2009). Specifically, for English readers, the perceptual span is estimated to be around 20 character spaces, extending 14 to 15 letters to the right of the fixation (McConkie & Rayner, 1975). A similar range is observed in Dutch (12 to 15 characters to the right of fixation, Den Buurman et al., 1981). In contrast, for Chinese reading, the perceptual span narrows to 1 character space to the left and 3–4 character spaces to the right of the fixation (Inhoff & Liu, 1998; Yan et al., 2015). Korean readers have a perceptual span extending about 6–7 characters to the right and 1 character to the left of the fixation (Choi & Koh, 2009). The perceptual span in Japanese is around eight characters for texts including both kanji and kana and six characters for texts with only kana (Osaka, 1987, 1992). Additional research into the Tibetan script, a phonological-based alpha-syllabary segmental writing system, indicates that its perceptual span does not extend as far as in English reading, ranging from 3 characters to the left of fixation to 7–8 characters to the right (Wang et al., 2021). Research indicates that graphemic properties, such as visual complexity, significantly influence the perceptual span in various writing systems (Pan & Yan, 2024; Wang et al., 2021). In their study, Pan and Yan (2024) focused on traditional Chinese sentences to evaluate the perceptual span during reading, comparing it with their earlier study on the simplified Chinese script (Yan et al., 2015). The only difference between these two scripts is their visual complexity. The findings demonstrated a reduced perceptual span in traditional Chinese, which is likely due to its increased visual complexity compared to simplified Chinese.

Across the writing system, a universal feature of the perceptual span is its asymmetrical distribution on either side of fixation. In which, the direction of the writing system plays an important role. In left-to-right reading systems (e.g., English, Chinese), the perceptual span is larger on the right side than on the left. Conversely, in scripts written from right to left (e.g., Hebrew and Arabic), the perceptual span is asymmetrically extended to the left (Jordan et al., 2014; Paterson et al., 2014; Pollatsek et al., 1981). Studies on Uyghur reading, which utilizes a modified Arabic script written from right to left, have reported that the perceptual span extends to 5 letters to the right and 12 letters to the left of the fixation (Zhou et al., 2021). These findings collectively indicate that the perceptual span extends towards the direction of upcoming words in reading. Research into the different writing systems has significantly enhanced our understanding of visual perception mechanisms in reading (Rayner, 2014).

Compared to horizontal reading, our understanding of the perceptual span in vertically written scripts is still limited. This knowledge gap is significant, the perceptual span when reading a vertically written script may have some unique properties due to the properties of the human visual processing system. The performance of human visual processing is not homogenous across the visual field but is better along the horizontal mid-line than along the vertical midline at a fixed eccentricity (i.e., horizontal-vertical anisotropy, HVA; Carrasco & Frieder, 1997; Rijsdijk et al., 1980; Rovamo & Virsu, 1979). HVA may reflect ecological constraints, as there is typically more relevant visual information across the horizontal dimension than across the vertical dimension in a natural scene. Consequently, when reading vertically oriented text, the perceptual span might show some unique properties, such as being smaller or less asymmetric than those when reading horizontally written scripts. Traditional Mongolian, as a vertically written script, offers a unique opportunity to explore these specific properties influenced by reading direction.

A few studies have been conducted to examine the properties of the perceptual span of vertically written languages. In Eastern Asia, scripts such as Japanese can be arranged either vertically or horizontally because of the block integrity of their basic writing units. The perceptual span for vertically written Japanese was found to be slightly smaller than the perceptual span estimate for horizontally written Japanese (Osaka, 1992). In one particularly relevant study, Su et al. (2020) used a gaze-contingent moving window paradigm to compare reading speed in different window conditions during traditional Mongolian reading. They found that reading speed was faster when the windows extended asymmetrically farther in the direction of reading (e.g., extended 0.5° to the up and 1.5° to the down side of fixation) than when the windows extended asymmetrically opposite to the direction of reading (extended 1.5° to the up and 0.5° to the down). These results show that the perceptual span is asymmetrical toward the bottom during traditional Mongolian reading. However, none of the window conditions produced a reading speed comparable to that of a normally presented condition. Therefore, they did not estimate the perceptual span size.

Building upon the foundation of previous research, this study extends the exploration to the unique writing system of the traditional Mongolian script, aiming to understand the perceptual span characteristics of a vertically oriented writing system. Prior studies have examined the extent of the perceptual span in horizontal reading systems, demonstrating its variability across different writing systems, influenced by factors such as reading direction and script complexity. These studies have shown the universal asymmetrical properties across various writing systems. However, these findings are predominantly limited to horizontally written scripts, creating a significant gap in our understanding of how vertical writing systems influence the perceptual span. This gap is particularly notable in the context of the traditional Mongolian script, which stands out due to its vertical, top-down reading direction.

Our research question focuses on determining the size of the perceptual span of skilled traditional Mongolian readers when reading naturally top-down written scripts. To achieve this, we employed a moving-window paradigm to systematically manipulate the window size to identify the smallest window that did not interfere with reading. Our hypotheses are built along two lines, informed by prior research. The first hypothesis is that the asymmetry property of the perceptual span is universal across script. This hypothesis predicts an asymmetrical shape extending in the direction of reading. Specifically, this hypothesis predicts that the perceptual span in traditional Mongolian reading will be larger on the downward side compared to the upward side. The second hypothesis assumes that the perceptual span of vertically writing script should be different from those horizontally written script because of the HVA property of the human visual processing system. This property results in a much narrower effective visual field along the vertical line compared to the horizontal line. Consequently, this hypothesis predicts that the perceptual span in traditional Mongolian reading will be smaller compared to that in horizontal reading systems. Through this study, we aimed to enhance our understanding of how reading direction affects perceptual span. Moreover, studies focusing on eye movement

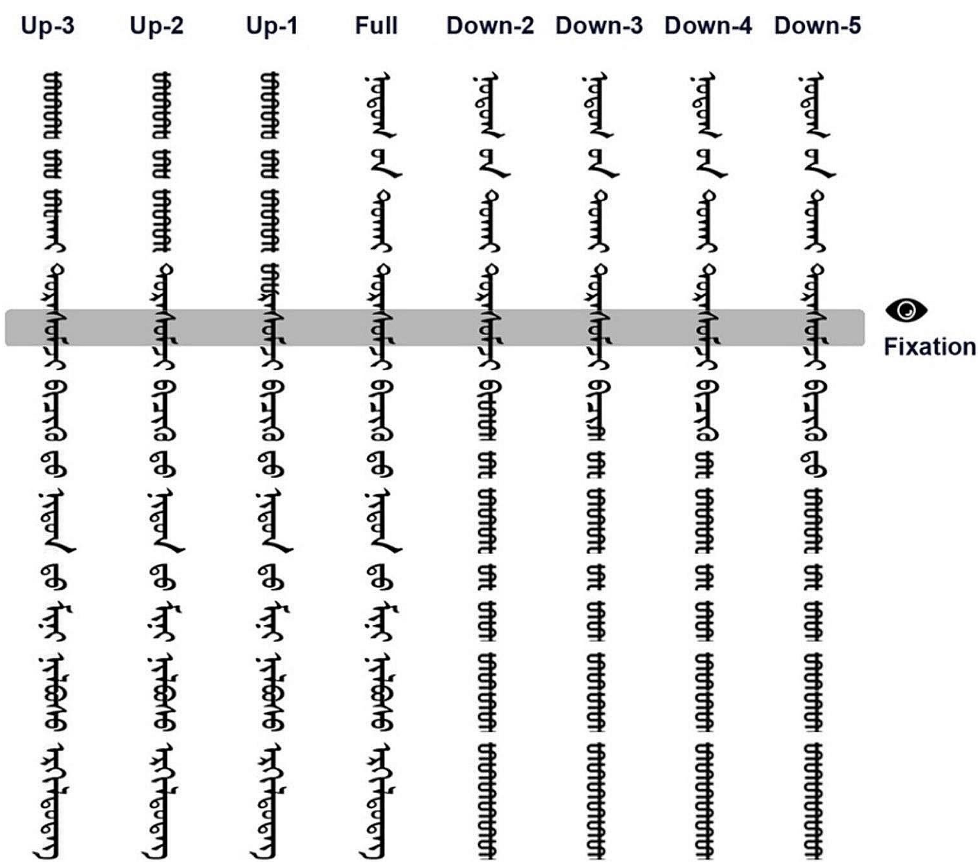

Fig. 1 An example sentence displayed with different viewing conditions. *Note*. The rectangle indicates the current fixation position. Syllables outside the moving window were masked by the symbol "ᠪ". The sentence translates into Englishas "*Tears welled up in my eyes as I wrote down memories of my hometown*

during vertically written traditional Mongolian reading are extremely rare, thus, our study represents an important initial exploration in this field.

Methods

Participants

Forty undergraduate and graduate students (with an average age of 24 years, ranging from 22 to 28 years old and including 30 females) from the Department of Mongolian Studies of Inner Mongolia Normal University participated in this experiment. The participants provided written consent in accordance with protocols approved by the ethics committee of the Institute of Psychology, Chinese Academy of Sciences. Concerning the background of participants in traditional Mongolian reading, all were native Mongolian speakers and attended Mongolian schools from elementary through high school, where they studied various subjects in Mongolian. Additionally, students from the Department of Mongolian Studies, who majored in Mongolian literature, spent the majority of their reading time engaging with literary works in Mongolian. This makes these participants well-suited to represent skilled traditional Mongolian readers.

Apparatus

The participants' eye movements were recorded using an EyeLink 1000 system, running at a sampling rate of 1,000 Hz. The viewing was binocular, whereas eye movement recordings and calibrations were based on the right eye.

Materials and design

Each participant read 200 traditional Mongolian experimental sentences and 40 practice sentences. Sentence lengths ranged from 8 to 14 words, and each sentence was presented as a single line of text in a commonly used 21-point fixed-width font (Menk Qagan Tig). The 200 experimental sentences contained 2,217 words, of which 647 words contained one syllable (29%), 861 words contained two syllables (39%), 488 words contained three syllables (22%), 178 words contained four syllables (8%), 39 words contained five syllables (1.9%), and four words contained six syllables (0.1%).

In this study, we used syllables as units to measure the perceptual span, primarily because syllables are key elements in traditional Mongolian text. Traditional Mongolian is an alphabetic writing system consisting of 31 letters, and does not emphasize letters as distinct units in text. As shown in Fig. 1, all letters are joined together within a word, and some contiguous letters in a word are intermixed such that they are not separable. For example, the combination of the vowel "ᠣ"(o) and the consonant "ᠪ"(b) is written as "ᠪᠣ"(bo). We selected syllables as the measurement unit for two main reasons: First, it is straightforward to segment a traditional Mongolian word into syllables based on physical characteristics. Second, syllables are the foundational units for teaching beginner traditional Mongolian readers. Beginners are trained to divide words into syllables for easier learning and memorization, following the traditional Mongolian word's syllable division rules (Chinggeltei, 1963). Therefore, using syllables as the unit to measure perceptual span is more practical in traditional Mongolian.

We manipulated the window size used in the gaze-contingent moving-window paradigm in eight viewing conditions, as depicted in Fig. 1. In the *Full condition*, the whole sentence was visible, regardless of the fixation location, allowing for natural reading. The maximum upward span was assessed with three window conditions, which respectively covered one, two, or three syllables up to the fixation (these conditions will be henceforth referred to as *Up-1*, *Up-2*, and *Up-3* conditions, respectively). For these conditions, text below fixations and within the window were presented normally (Rayner, 2014), while text above these windows was masked with symbols, though the inter-word spaces were preserved. Similarly, the maximum downward span was determined with four different viewing windows, which respectively covered two to five syllables below fixations, namely *Down-2*, *Down-3*, *Down-4* and *Down-5*. For these conditions, text above the fixation and syllables within the window were presented normally, but syllables below these windows were masked with symbols, with inter-word spaces preserved. According to the study of Su et al. (2020), the perceptual span of traditional Mongolian reading is asymmetric and the span below fixation is larger. Therefore, to measure the downward span in a limited condition setting, we did not include the condition of one syllable in the downward window setting. The symbol "ᠣ" was used as the mask because its shape is similar to the visual features of traditional Mongolian texts. We employed a blocked design with one block for each condition. The sentences were randomly assigned to eight blocks of experimental conditions using a Latin square design. That is, each participant saw all the sentences, but each sentence was shown in each condition equally often. At the beginning of each testing block, five practice trials were conducted for the participants to familiarize themselves with the experimental manipulation.

Procedure

We calibrated the eye-tracking system using a standard full-screen 5-point grid. The maximum acceptable calibration

Fig. 2 Reading speed as a function of viewing condition. *Note.* An asterisk indicates a significant difference from the baseline Full condition. Reading speed was measured in words per minute (wpm). The brown bar represents the baseline condition. The green bar represents the condition of the measurement of the upward span. The orange bar represents the condition of the measurement of the downward span. *$p < .05$; **$p < .01$; ***$p < .001$

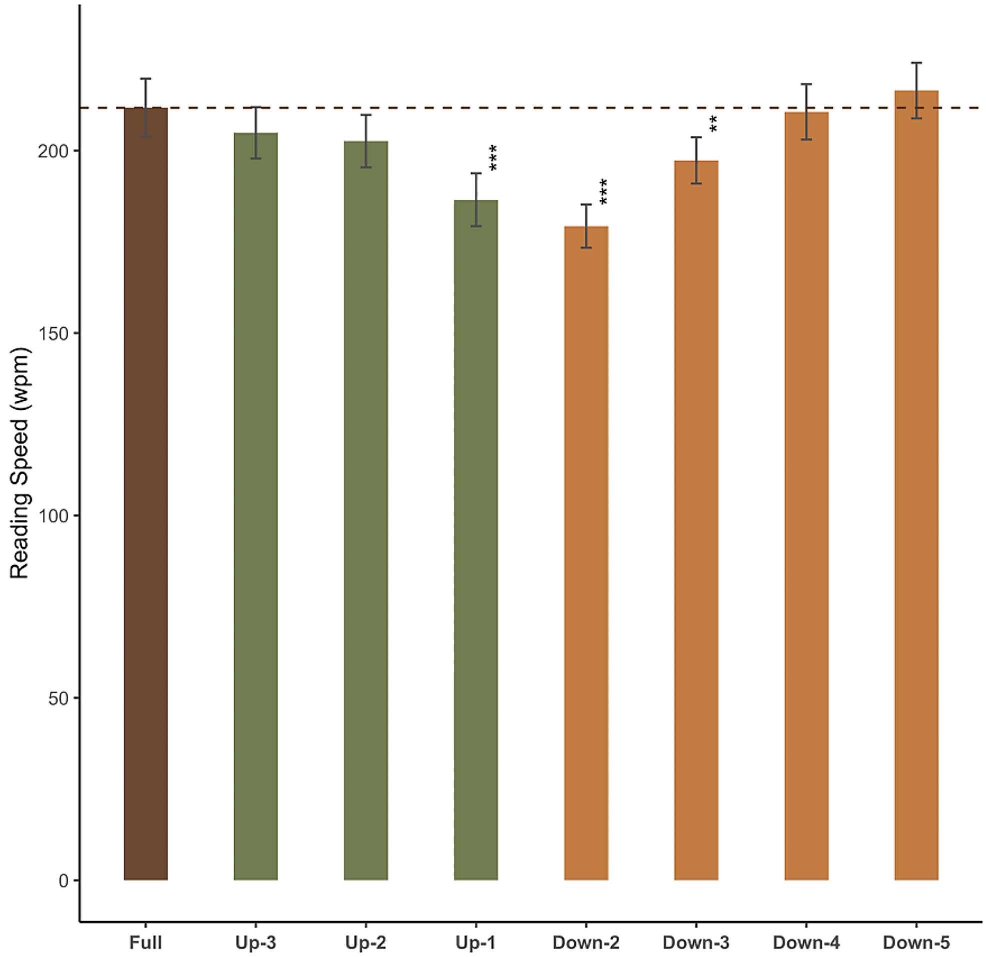

Table 1 Linear mixed-effects for reading speed (wpm)

Fixed-effects	*B*	*SE*	*df*	*t*	*p*
Up-1 vs. Full	-0.14	0.033	41.46	-4.227	**< 0.001**
Up-2 vs. Full	-0.042	0.024	44.003	-1.746	0.088
Up-3 vs. Full	-0.026	0.02	46.206	-1.301	0.200
Down-2 vs. Full	-0.162	0.024	43.875	-6.821	**< 0.001**
Down-3 vs. Full	-0.066	0.021	45.541	-3.184	**0.003**
Down-4 vs. Full	0.000	0.017	48.589	0.029	0.977
Down-5 vs. Full	0.025	0.019	47.062	1.337	0.188

Bold indicates significant difference at $p < .05$

error was 0.5°. The participants were instructed to read the sentences silently for comprehension. Comprehension questions were presented following the 56 sentences to ensure participants' engagement in the task. Overall, the participants showed a high comprehension rate ($M = 93\%$, $SD = 7\%$; in the range of 84–100%), indicating that participants understood sentences well.

Data analysis

Six trials (0.06%) were excluded from the analyses because of eye-tracker errors. Sentences with reading times greater than three standard deviations for each participant in each condition were removed. Approximately 1.3% of trials were excluded from the analyses.

The perceptual span was determined by comparing reading speed, measured by the number of words per minute (wpm), in different window conditions with the *Full* condition. To this end, a linear mixed-effects model (Baayen et al., 2008) was constructed for analysis. Window conditions were treated as fixed effects, wherein planned treatment contrasts were used with the *Full* condition as the baseline. Participants and sentences were entered into the model as crossed random effects, including intercepts and slopes. Following Barr et al. (2013), we first constructed a model with a maximal random factor structure. When the maximal model failed to converge, we used a zero-correlation parameter model and dropped the random components that generated the smallest variance. Statistical analyses were conducted using the *lmer* function (Bates, 2015) and *lmerTest* package (Kuznetsova et al., 2017) in *R* (version 3.5.1; R Core Team, 2018).

Results

The mean reading speed and its standard errors are shown as functions of the window condition in Fig. 2. As can be seen, for the upward-window conditions, the reading speed was significantly slower than that in the *Full* condition in the *Up-1* condition, but not in the *Up-2* and *Up-3* conditions. For the downward-window conditions, the reading speed was slower than that in the *Full* condition in the *Down-2* and *Down-3* conditions, but not in the *Down-4* or *Down-5* conditions. These results show that the perceptual span is one syllable above the fixation and three syllables below the fixation for fluent traditional Mongolian reading. Table 1 shows the linear mixed-effects model results for the reading speed. These findings are consistent with the predictions that the perceptual span in traditional Mongolian reading is larger on the downward side than on the upward side. Concerning the size of the perceptual span, traditional Mongolian reading shows a similar size to that observed in Chinese reading. Since both studies measure perceptual span in terms of syllables, this allows for a meaningful comparison. The comparable size of the perceptual span in traditional Mongolian and Chinese readings suggests that Horizontal-Vertical Anisotropy in human visual processing systems may not significantly impact reading efficiency in vertical writing systems. This observation contradicts to the hypothesis based on the HVA property of the human visual processing system, which anticipated that the perceptual span in traditional Mongolian reading would be smaller than in horizontal reading systems.

Discussion

In this study, an eye-tracking experiment was conducted to investigate the size of the perceptual span when reading traditional Mongolian, a vertically written script. We adopted a gaze-contingent moving-window paradigm to measure the size of the perceptual span when reading traditional Mongolian sentences. The results showed that the perceptual span was asymmetric downward, extending one syllable above the fixation and three syllables below the fixation.

Our results contribute to the understanding of the underlying mechanisms of the perceptual span. First, we observed that the asymmetry of perceptual span during vertically written traditional Mongolian reading aligns with that found in horizontally written texts (McConkie & Rayner, 1976). This consistency in asymmetry, towards reading direction, demonstrates a universal characteristic of human visual information extraction during reading. Alongside previous studies (Henderson & Ferreira, 1990; Inhoff et al., 1989; Pollatsek et al., 1981; Liu et al., 2018), our findings further support the idea that allocation of attention to the direction of reading underlies this spatial asymmetry. Readers tend to focus more attention on upcoming words along the reading direction, thereby extending the perceptual span in that direction. Meanwhile, the present study denies the hemispheric specialization hypothesis (Eviatar & Ibrahim, 2007; Ibrahim & Eviatar, 2009), which suggests that the asymmetrical perceptual span is caused by lateralization of brain function. Given that traditional Mongolian script is read vertically, the text above and below the fixation should be mapped onto the same hemisphere. We still found an asymmetrical perceptual span toward the reading direction. This suggests that the asymmetry of the perceptual span is attributed more to the deployment of visual attention than the lateralization of brain function (Zhou et al., 2021).

Second, the present study found that the perceptual span in traditional Mongolian reading, which includes 5 syllables with a fixated one, is similar to Chinese reading, where the span also includes 5 characters in total (Inhoff & Liu, 1998). This is an interesting comparison because traditional Mongolian use an alphabetic writing system and the Chinese use a logographic writing system. In Chinese, each character usually corresponds to a single syllable and is usually a basic morpheme (Wu & Bulut, 2020). So, in both Mongolian and Chinese studies, we are essentially measuring the perceptual span in terms of syllables. This similarity across different writing systems suggests that the perceptual span is determined by the amount of linguistic information that can be obtained from the text, not just the physical space. When considering the size of the perceptual span in English and Chinese reading, it appears equivalent if measured in a number of words instead of a number of characters (Rayner et al., 2016; Yan et al., 2015). Coupled with the findings from this study, it implies a potentially universal optimal rate of information extraction that is more or less consistent across different languages. Further detailed and carefully controlled comparative experiments are needed to verify this hypothesis.

Third, the similarity in the perceptual span between horizontal Chinese reading and vertical traditional Mongolian reading suggests that Horizontal-Vertical Anisotropy in human visual processing systems may not significantly impact visual information extraction during reading in vertical writing systems (Yu et al., 2010). One plausible explanation is that traditional Mongolian readers have developed processing systems efficiently optimized for vertical reading. This adaptation potentially compensates for the limitations in the visual processing system due to HVA. To further support this hypothesis, comprehensive experiments are necessary.

Fourth, compared to the well-studied theories in eye movement control during Western languages (Kazandjian

& Chokron, 2008), there is a significant gap in understanding Mongolian reading, especially in the context of vertically written scripts. Theories and computational models of eye movement control during reading are primarily based on assumptions concerning the perceptual span (Pollatsek et al., 2003). The present study represents the initial step in bridging this gap for Mongolian reading, offering fundamental evidence for future research on Mongolian reading. Moreover, it provides an optimal opportunity to investigate universal and language-specific characteristics of reading across different languages (Li et al., 2022).

Limitations and future directions

Although the study is important to understand the universal and script-specific mechanisms of reading, it has some limitations. The Mongolian language employs two distinct writing systems – the horizontal Cyrillic script and the vertical traditional Mongolian script – the study's robustness could be significantly enhanced by including analyses of the Cyrillic script (Chung et al., 2017; Fernandez et al., 2023). For a more comprehensive understanding, future research should extend to investigating the perceptual span in the Cyrillic script. A direct comparison between the two would provide deeper insights. Another limitation of the present study is that we did not consider individual differences (Choi et al., 2015; Sperlich et al., 2016). All participants in the study were expert traditional Mongolian readers. Further studies are needed to examine how reading ability affect the perceptual span of traditional Mongolian reading in the future.

Conclusion

The present study has successfully determined the size of the perceptual span in traditional Mongolian reading, a vertically written script, revealing it to include five syllables, with one syllable above and three below the fixation. These findings align with the studies in horizontal reading, suggesting a universal aspect of visual information extraction across different writing systems. This research marks the first significant step towards filling the gap in our understanding of eye movement control in traditional Mongolian reading and lays a solid foundation for future explorations in this area.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Borogjoon Borjigin, Guangyao Zhang, You Hou and Xingshan Li. The first draft of the manuscript was written by Borogjoon Borjigin and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets generated during and/or analyzed during the current study are available at https://osf.io/ch2q5/.

Declarations

Ethic approval The participants provided written consent in accordance with protocols approved by the ethics committee of the Institute of Psychology, Chinese Academy of Sciences.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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