Using an Eye-Tracker to Investigate the Potential Effects of Writing Systems on L1 and L2 Users

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Abstract

The interplay between language and thought has long been a subject of tense debate in the literature, particularly among linguists interested in investigating the impact of the first language on how speakers of different languages envision the world and react to it. This study sought to contribute to this debate by comparing between eye-movement data collected while participants in two linguistic groups (English monolinguals: n = 13; Chinese EFL speakers: n = 14) were reading texts. To achieve this aim, the sampled participants completed an eye-tracking experiment in which they were presented with English street signs containing texts that were written vertically and prompted to read these signs silently. The results of the study revealed several scenarios in terms of the direction of eye movement while reading the signs, the most frequent of which were middle-top-bottom, top-middle-bottom and middle-bottom. The results have also shown a predilection on the part the English monolinguals for middle-top-bottom eye movement, whereas the Chinese participants preferred the top-middle-bottom eye movement. This discrepancy provides little support for the relativity theory because the difference between the two groups was not statistically significant (p = 0.788). Implications for landscape designers and educational institutions are discussed at the end of the study.

Keywords: *linguistic relativity, writing systems, effects of L1 on L2, Landscape Linguistics, Cognitive Linguistics, Mandarin, eye-tracking*

استخدام جهاز متتبع العيون لفحص التأثيرات المحتملة لأنظمة الكتابة على مستخدمي اللغتين الأولى والثانية

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الملخص

لطالما شكّل التفاعل بين اللغة والفكر موضوعًا للجدل المحتدم في الأدبيات العلمية، لا سيما بين اللغويين المهتمين بدراسة تأثير اللغة الأولى في كيفية تصوّر العالم لدى الناطقين بلغات مختلفة. وقد سعت هذه الدراسة إلى الإسهام في هذا الجدل من خلال مقارنة بيانات حركة العين التي جُمعت أثناء قراءة المشاركين في الدراسة لنصوص مكتوبة. وتشكّل المشاركون من مجموعتين لغويتين (الناطقون بالإنجليزية لغةً وحيدة وعددهم = 13؛ والناطقون بالصينية ممن يتعلمون الإنجليزية لغةً أجنبية وعددهم = 14). ولتحقيق هذا الهدف، خضع المشاركون لتجربة تتبّع حركة العين، حيث عُرضت عليهم لافتات شوارع مكتوبة باللغة الإنجليزية تحتوي نصوصًا وضعت في صفوف عمودية، وطُلب منهم قراءتها بصمت. وكشفت نتائج الدراسة عن عدة أنماط في اتجاه حركة العين أثناء قراءة اللافتات، كان أكثرها شيوعًا: 1) نمط الحركة من الوسط إلى الأعلى ثم الأسفل، و2) نمط الحركة من الأعلى إلى الوسط ثم الأسفل، و3) نمط الحركة من الوسط إلى الأسفل. كذلك، أظهرت النتائج ميلًا لدى الناطقين بالإنجليزية إلى النمط (1)، في حين فضّل المشاركون الصينيون النمط (2). غير أن هذا التباين لا يدعم نظرية النسبية اللغوية بشكل كبير، نظرًا لعدم وجود فرق دال إحصائيًا بين المجموعتين ($p = 0.788$). وتُختتم الدراسة بمناقشة الآثار المترتبة على هذه النتائج بالنسبة لمصممي المشهد الحضري والمؤسسات التعليمية.

الكلمات المفتاحية: النسبية اللغوية، أنظمة الكتابة، تأثير اللغة الأولى في الثانية، المشهد اللغوي، اللسانيات النفسية، لغة الماندرين، متتبع العيون

Introduction

The intricate interplay between language and thought has been a topic of enduring debate, with contrasting perspectives shaping the discourse. On one end of the spectrum lies the universalist view, positing a shared human conceptual structure across cultures, one distinct from linguistic influences (see Jameson & D'Andrade, 1997; Levinson et al., 2002). For instance, Berlin and Kay (1969) supported the universalist approach to language and thought using evidence from colour and cognition across various linguistic groups, claiming that colour terms are universally predictable, where speakers of a language develop terms for light and dark colours first then other colours are introduced. Additionally, Regier et al. (2007) suggested that the semantic distinctions in different languages are limited by available options to language speakers, suggesting that thought shapes language. More recently, Malt (2024) argued that our view of the world is guided by internal processes of thought. Conversely, the linguistic-relativity, the weaker version of Sapir-Whorf hypothesis, contends that native languages shape thought processes, suggesting that linguistic distinctions may lead to varied perceptions of reality. For example, Roberson, et al. (2000) and Roberson et al. (2002) argued that there are language-specific colour boundaries in Berinmo, a local language spoken in Papua New Guinea, and English. Similarly, Tseng et al. (2016) found that there is a correlation between first language and spatial recognition. Hence, Pae (2020) argued that although this version of the hypothesis has gained some criticism in the past, it has regained attention in the past few years. Yet, the notion that language shapes our though remains a matter of debate. As Schnell (2024) puts it "This latter version of linguistic relativity is debated and needs more scrutiny and scientific evidence". Therefore, the current paper contributes to this debate using eye-tracking data.

The acquisition of a L2 writing system involves knowledge of more than one writing system (WS) and sometimes more than one script. This impacts three key aspects as Cook and Bassetti (2005) assert: it can influence reading and writing in both writing systems, modify metalinguistic awareness, and affect non-linguistic factors such as directionality. Thus, biliterate individuals, may read signs and scan objects differently from their monoliterate counterparts as explored by different studies (e.g., Eviatar, 1995; Al-Rasheed

et al., 2014; Zhang and Yuchan, 2022). Notably, these effects extend beyond the L1's phonological or orthographic system to other linguistic characteristics (DeAngelis and Dewaele, 2011). Research indicates that directional differences play a role in the interaction between two distinct writing systems, such as English and Mandarin. Bilingual children have been observed to be affected by these differences (Cook, 2016). Further, in a study by Chan and Bergen (2005), three experiments involving different WSs revealed that WS orientation is deeply ingrained in the cognitive system of WS users, influencing their performance in spatial tasks.

The long-lasting debate between the universalists and relativists calls for more research based on technology-informed experiments (see Casaponsa, et. al. 2024). As Lucy (2015:13486) puts it: "Despite widespread interest, quality empirical research has been in short supply." Therefore, this article delves into writing systems' relationships to cognition using an eye-tracking experiment, seeking to determine whether biliterate people see the world differently from monoliterates, who use only one writing system. A focal point of this experiment is the examination of the effect that writing system features, such as directionality and the type of characters used, have on L1 users and L2 users, namely English monolinguals and Mandarin-English bilingual speakers. The integration of eye-tracking technology into these investigations provides a nuanced understanding of how linguistic features are manifested in visual processing, shedding light on the intricate relationships between language, thought and perception. The use of eye-tracking technology, with its ability to dissect the dynamics of visual input and cognitive integration, promises to enhance our comprehension of the complex relationship between language and thought. Employing an eye-tracker to gauge response times and eye movements during reading or writing offers valuable insights. This methodology allows an exploration of how different writing systems impact language learning and usage (Anderson, 2005; Attardo & Pickering, 2023). The conjecture is that the intricacies of a writing system may shape the perceptions of individuals native to it. This understanding contributes to a broader comprehension of how writing systems influence the acquisition and utilisation of literacy skills.

This study utilises eye-tracking technology to investigate whether L2 users read street signs differently from L1 users. More specifically, it investigates whether Mandarin-English bilinguals and English monolinguals have different reading strategies for English street signs. It seeks to answer the following research question:

(1) Is there a difference between the ways in which Mandarin-English bilinguals and English monolinguals read street signs?

The study hypothesises that Mandarin-English bilinguals and English monolinguals will look at the street signs differently. That is, the overall order in which they look at the three areas of the sign (top, middle and bottom) will differ across L1s.

Literature Review

The relationship between language and thought has long been debated. At one end of the scale is the universalist view, which emphasises that the human conceptual structure is relatively similar across cultures and combined with a semantic structure (Gentner & Goldin-Meadow, 2003; Psarompa, et al. 2024). The universalist view also proclaims that non-linguistic concepts are formed independently from the words that label them. The linguistic relativity hypothesis, at the other end of the scale, holds that thought processes are shaped by native languages; this view was first put forward by Edward Sapir and Benjamin Lee Whorf. Specifically, it argues that the linguistic differences between two language structures would be correlated with non-linguistic differences, suggesting that speakers of one language would experience reality differently from speakers of another language.

Sapir and Whorf were not the first to suggest this view. For example, the German linguist Wilhelm von Humboldt (1767–1835) fostered the belief that speakers of different languages have varying views of the world they live in (Brown, 2014). Boas (1858–1942) later observed that language "determines those aspects of each experience that must be expressed" (Brown, 2014: 127). He made further reference to differences across languages and summarised this belief in three ways: (a) languages classify experience, (b) different languages will have a different classification of the same experience (i.e., this can lead to

different experiences of the same event) and (c) these varying experiences of the same events, due to language, remain unobserved by the speakers of a language because of the automatic nature of language. Humboldt and Boas were followed by Sapir (1884–1936) and Whorf (1897–1941), who proposed what has become known as the linguistic relativity or the Sapir–Whorf Hypothesis.

Experimental studies of the Whorfian effect on Mandarin speakers

Several studies have considered the potential linguistic effects of the first language on the thought processes of its speakers, and these have yielded various findings (e.g., Li, 2024; Saho, et al. 2022; Xue & Williams, 2021) . One of the earliest studies that investigated the effects of language on thought was that of Bloom (1981), who argued that the lack of overt counterfactual marking in Chinese made it difficult for Mandarin speakers to interpret 'if/then' structures with false premises. Nevertheless, Mandarin speakers, in fact, process counterfactuals quite reliably (Feng and Yi, 2006), and Bloom's effects have not been replicated using natural language (Au, 1983).

According to Fuhrman et al. (2011), Mandarin generally uses a vertical metaphor for time (e.g., the previous month is literally 'up a month'), whereas English favours a horizontal metaphor (e.g., 'the month before'). To investigate whether the vertical time metaphor has restructured Chinese thinking, Boroditsky (2001) tested speakers completely in English. The findings showed that as compared to English monolinguals, Mandarin-English bilinguals made faster 'earlier'/'later' judgments about the relative order of months after making overtly spatial judgments about vertical primes. Boroditsky et al. (2011) showed participants a sequence of two pictures (e.g., photographs of the same person at different ages) and asked them to judge whether the second was 'earlier' or 'later'. The Mandarin speakers were faster if the 'earlier' response key was above the 'later' key. These findings are aligned with those of a study by Fuhrhman et al. (2011), who found that Mandarin speakers were more likely than English speakers to point above or below a reference point to indicate relative time.

Another area in which Mandarin influences its speakers is in the use of classifiers. Zhang and Schmitt (1998) reported that Mandarin speakers judged noun pairs that shared the same classifier as being more similar. Kuo and Sera (2009) studied shape classifiers

with Mandarin and English speakers and demonstrated that Mandarin speakers' classifications of objects were affected by shape to a greater degree than those of English speakers. Imai et al. (2010) reported similar results for Chinese and German children only in classification tasks. The effects of these classifiers may involve linguistic processing. Gao and Malt (2009) asked Mandarin speakers to memorise nouns in sentence contexts. Noun recall fell more completely into classifier-defined clusters in comparison with English, but only when nouns had appeared in sentences with explicit classifiers.

Using eye-tracking technology, Huettig et al. (2010) pointed out that Mandarin speakers looked at pictures of objects that shared the same classifier as an object named in an auditorily presented sentence, but only when the classifier was also presented. Eye-tracking technology is considered a powerful tool in scientific research, opening the way for new insights and challenges in these fields (Hansen-Schirra and Grucza, 2016; Kiliańska-Przybyło and Grotek, 2021). The aim of using eye-tracking technology is to track eye movements and determine a participant's gaze direction. Tracking the eye movements during reading and image perception offer useful information about the processes by which people recognise visual input and incorporate it into existing knowledge and memory. In an alternative account of how Chinese readers process sentences, Wei et al. (2023) used evidence from eye-tracking to investigate the role of syntax versus semantics in processing written sentences. The results confirmed the priority of syntax over semantics for Chinese readers.

The two basic components of eye movements in most tasks are the saccades, which are the movements themselves, and the fixations, which are the periods of time when the eyes remain fairly still and new information is acquired from the visual array (Rayner, 2009). Fixations refer to 'those moments when the eyes are relatively stationary and reflect when information is being encoded' (Smith, 2012: 55), whereas saccades refer to 'the eye's rapid movements from one fixation to the next' (Nielsen and Pernice, 2010: 7).

The analysis of fixations offers important information with respect to the features of the text being processed. According to Matin (1974), new information is only acquired during fixations because vision is suppressed during a saccade and the eyes are moving so

quickly across the stable visual stimulus that only a blur would be perceived (Rayner, 2009).

Chinese writing system

The writing system of a speaker's native language may affect their thinking. Several studies have focused on the potential impact of writing systems on speakers' thinking and found that each writing system is a great force in shaping the thought of its users (e.g., Deng, et al. 2019; Loske, et al. 2024; Pae & Wang, 2022).

The Chinese writing system is considered one of the most valuable aspects of Chinese culture. A careful investigation of the origin and structure of the Chinese writing system and its impact on Chinese thinking patterns reveals much regarding how Mandain speakers perceive and think about the world around them. Most languages have an alphabet, which is a set of characters that represent units of sounds, or phonemes, but the Chinese writing system is made up of numerous characters, or logographs, that represent units of meaning, namely words. Typologically, it is referred to as a logographic writing system, which provides a character to represent each word and thus convey meaning (Sampson, 1985). However, as the Chinese writing system denotes morphemes, the smallest linguistic elements of meaning, it is better classified as a morpho-syllabic (DeFrancis, 1989), morphemic (Cook and Bassetti, 2005) or morphographic writing system (Joyce, 2011). The characters are sometimes commonly thought to be pictures of the words they represent, but they actually represent a unit of sound (a syllable) that is also a unit of meaning (Coulmas, 1996; 2003). Some researchers (e.g., Nisbett, Peng, Choi and Norenzayan, 2001) attribute such differences to culture, which is believed to have an influence on where we look. Culture influences various high-level cognitive behaviours, such as social judgments and the verbal recalling of visual scenes. Most available studies have contrasted Americans with East Asians, concluding that speakers from these two cultures view the world differently. In a study conducted on American and Chinese speakers, Chua, Boland and Nisbett (2005) found that Chinese participants spent more time looking at the scene background and less time looking at the focal objects in a scene as compared to English-speaking participants. These findings were discussed considering a general theory of cognitive cultural differences (Nisbett, 2003). Asian cultures lead people to place value on the group rather than the individual, whereas American culture places

more importance on individuality. This cultural difference in thinking leads Chinese participants to look longer at the background and spend less time looking at the focal objects as compared to Americans (Chua et al., 2005).

The present study

This study investigates the potential differences between Mandarin-English bilinguals and English monolinguals regarding image perception using eye-tracking equipment. If the notion of linguistic relativity is applied, the different linguistic structures of English and Mandarin must lead to cognitive differences between participants. Therefore, this paper examines whether these differences between languages lead to differences in eye movement. The data were obtained using eye-tracker technology, which is thought to provide researchers with a window into the mind. Poole and Ball (2006: 211) defined eye-tracking as a technique 'whereby an individual's eye movements are measured so that the researcher knows where a person is looking at any given time and the sequence in which their eyes are shifting from one location to another'. The advantages of using eye-tracking are numerous and outweigh those of traditional online processing measures. Eye-tracking does not require a secondary task, and thus, it allows for more natural processing. It offers a very rich moment-to-moment data source (Conklin and Pellicer-Sánchez, 2016) and opens the way for new insights and challenges (Hansen-Schirra & Grucza, 2016). It has proven to be particularly suitable for disentangling various processes and stages of reading (Roberts and Siyanova-Chanturia, 2013).

Methodology

Participants

The researchers recruited 27 participants, who were divided into two groups: Mandarin-English bilinguals (n = 14; 13 females and one male) and English monolinguals (n = 13; ten females and three males). All the participants were middle-aged students, aged between 20 and 40 years who did not report having vision or neurological problems. The sampled participants were students at Newcastle University, UK (both undergraduates and

postgraduates), and were recruited randomly by replying to leaflets distributed in Newcastle University asking for volunteers. All the participants signed consent forms and filled out background questionnaires that collected their demographic information. Because Newcastle University has a minimal English requirement of level 6 in IELTS for entry, it is assumed that the Chinese participants are competent English language users (IDP IELTS, 2023). The research was performed in accordance with all relevant ethical guidelines and the 1964 Helsinki Declaration and its later amendments. The participants participated voluntarily in the study. Their real names and personal data were not shared with any third parties. Table 1 below summarises the demographic information of the participants.

Table 1 Participants

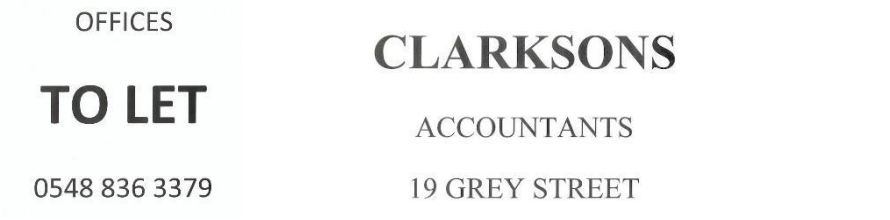
	Chinese EFL speakers	English Monolinguals	Total
Females	13	10	23
Males	1	3	4
Total	**14**	**13**	**27**

As can be seen in the table above, gender is not distributed evenly in the sample, this is because gender is not taken as a variable in the present study.

Materials

Thirty-six street signs were devised to be used as stimuli based on the research into street signs conducted by Cook (2013). Constructed signs were used rather than reproductions of real signs so that the variables could be better controlled. Half were modelled on real-estate-agent signs advertising places to rent or for sale, and half were modelled on 'brass-plate' signs stating the registered offices for businesses, as shown in Figure 1. Both these kinds of informational signs occur in most city-centre streets. Real-estate-agent signs had one line consisting of the announcement *To Let/To Rent/For Sale/Sold*; a second line stating the type of property, specifically *Flats/ Offices/ House*, and a third line giving a phone number of *054 534 3104*. The brass-plate signs had one line consisting of a fictitious business name, such as *Langston*; a second line with a business address, such as *35 Victoria Road*, and the third line containing a type of business

Solicitors/Accountants/Consultants/Dental Clinics. The vocabulary items were rotated to ensure equal coverage within both the real-estate-agent and brass-plate signs.



Estate agent sign Brass-plate sign

Figure 1 Sample stimuli

All letters were in upper case. The real-estate-agent signs were in sans-serif Verdana font; the brass plates were in Times New Roman. Serifs are 'the broadening of triangular forms at the terminals of letters' (Hill 2010: 186), which are seen say on the feet of the <K> or the ends of the <S>s on the brass-plate sign in Figure 1; sans-serif fonts also usually have even line widths, while serif fonts have varying widths. Sans-serif fonts are often seen as more modern, while serif fonts are seen as more traditional.

Each stimulus had three zones of text without punctuation: top, middle and bottom. Each type of line was rotated across the zones, with the exceptions of the phone numbers and addresses, which appeared only in the middle and bottom positions, as they typically do in English signs. Figure 1 provides two examples. The real-estate-agent sign, on the left, gives the property type, *Offices*, in the top zone; the announcement *To Let* in large bold type in the middle zone and the phone number in the bottom zone, all in sans-serif capitals. The brass-plate sign, on the right, has the business name in the top zone in large bold letters; the business type, *Accountants*, in the middle zone and the address in the bottom zone, all in serif capitals.

To sum up, all the signs were presented without considering the type of font, the material of sign or bold versus non-bold letters, as these variations showed no or very little effect during material pretesting. Thus, comparison between the two groups focussed on the three different zone locations for text: top, middle and bottom. The data generated by the eye-tracker allowed for a comparison between the two groups based on the direction of reading the three-zone stimuli. In turn, this would help in answering the question whether the information which grab one's attention first are influenced by the direction of the

writing system in their first language. Unpaired t-test was run using SPSS v.29 to check whether the differences between the two linguistic groups were statistically significant.

Procedure

The entire session lasted between 25 and 30 minutes; the participants were tested individually. They were seated on a chair at a fixed position from the monitor screen. After they had filled out their consent forms and given their biographical and language background information, the task procedure was explained, and they were informed that their task was to look at the signs that would appear on the screen in front of them. The experiment began with calibration to ensure the accurate recording of the participants' eye movements, followed by a countdown to indicate the beginning of eye movement recording and three practice examples using mock-up signs to ensure the participants understood the procedure, during which they could pause the examples and ask questions. The participants were told to tell the experimenter to stop the task at any time they needed to clarify something or if they were simply getting tired.

Each trial began with a screen-calibration procedure to ensure the participant's fixation point was accurate. After this, the first stimulus appeared centred on the screen for three seconds. There was a pause of two seconds before the next stimulus appeared. Stimuli were presented in pdf form in individually randomised orders. The eye-tracking device used in the experiment was a Tobii X120 3.2 with a Dell 17-inch display. This is a non-intrusive device that does not require the wearing of a headset. The three zones were treated as AOIs (areas of interest). The Tobii eye-tracker uses infrared illuminators while tracking to generate reflection patterns on the eye corneas of the participant. Other visual data about the participants are collected, together with the reflection patterns as the processing algorithms identify relevant features and calculate the 3D positions of each eyeball and, finally, the position of the gaze point (TobiiAB, 2016).

Results

Eye-Tracker Experiment (English Signs)

The current study was intended to detect the direction of eye movement when reading English vertical signs by two linguistic groups: native English users and Chinese English-as-a-second-language users. The eye-tracking experiment revealed that participants from

both groups had various directions of eye movement when reading the signs. The participants viewed 36 different monolingual (English) signs. We considered three zones of interest: the top (T), middle (M), and bottom (B) in each sign, and recorded the two linguistic groups' variation in gaze direction. The experiment showed that monolingual participants (native English speakers) tended to look first at the middle, then to the top and then to the bottom of a sign. The result is different for bilinguals (native Mandarin–L2 English speakers), as they pay attention first to the top, then to the middle and then to the bottom of the signs in a sheer vertical top-to-bottom alignment. In both groups, however, TMB and MTB, were the most common orders, as displayed in Table 2 below.

Table 2

The overall results for gaze order among L1 and L2 users

Reading direction*	Mandarin-English bilinguals **N = 14**	English Monolinguals **N = 13**
TopMiddleBottom (TMB)	112	184
TopBottomMiddle (TBM)	6	23
TopMiddle only (TM)	8	13
TopBottom only (TB)	2	5
Top only (T)	0	3
MiddleTopBottom (MTB)	131	95
MiddleBottomTop (MBT)	44	32
MiddleBottom only (MB)	43	28
MiddleTop only (MT)	7	15
Middle only (M)	2	6
BottomMiddleTop (BMT)	13	17
BottomMiddleTop (BTM)	11	12
BottomMiddle (BM)	11	5
BottomTop (BT)	4	1
Bottom only(B)	1	4
Total	**395**	**443**

*T=top, M=middle, B, bottom (e.g., TMB mean that readers start reading signs from top, then middle, then bottom).

Although the two groups behaved differently in the eye-tracking experiment, an unpaired t-test revealed that the difference between the two groups was not statistically significant (t = 0.194, df = 28, p-value = 0.84). Since the p-value is greater than .05, the findings of this study do not support that the L1 influences one's behaviour in terms of the direction of reading signs.

The figures below summarise the data displayed in Table 2 above. Gaze order, aka reading direction, is shown in Figure 2. Figure 3 displays the differences between the two groups in terms of the first zone they look at when reading signs. Finally, Figure 4 shows how the data were distributed with regards to gaze order.

The gaze order is shown in Figure 2 below. Though there are 15 variables accommodating all locations on the study materials, we can identify several differences that set the two groups of participants apart. While more bilinguals chose to look at the zones top-to-bottom, monolinguals seem to prefer to look at the middle zone. However, starting from the bottom and then looking up to middle or directly to the top was not significantly different between L1 and L2 users.

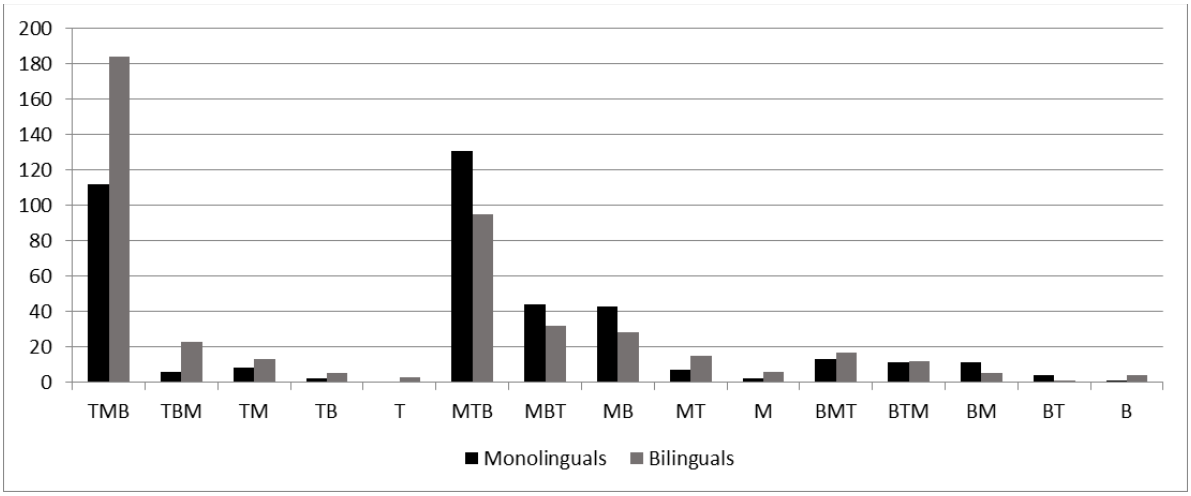


Figure 2 Gaze order at zones of interest: top, middle and bottom

Figure 2 shows that looking first at top is preferred by bilinguals (Mandarin-English speakers), whereas looking at middle first is more favoured among monolinguals. The bottom areas, on the other hand, are fairly neglected at first sight. Figure 3 below sketches the first-look differences between the two groups. While the monolinguals prefer the middle zone, the bilinguals prefer the top zone, and both seldom choose the bottom zone.

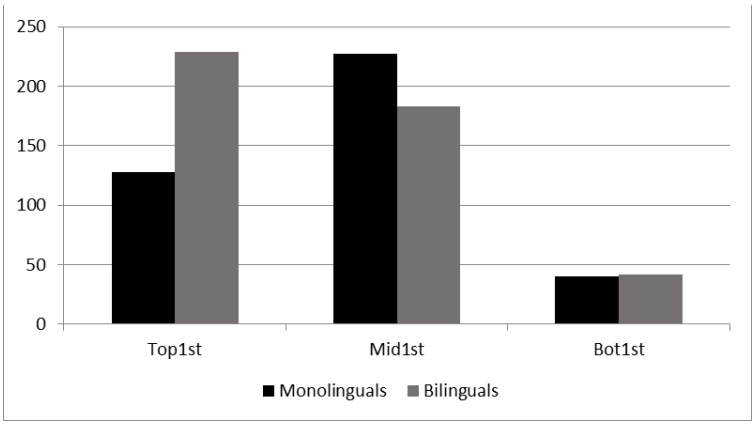


Figure 3 Preferred First-Look Zones of Interest

The percentage of individuals looking at each of the three areas for each group is shown in Figure 4. The top zone first attracted the interest only 32% of monolinguals, but it was prioritised by 51% of bilinguals. The middle is important (58%) for monolinguals, while it is relatively less important (40%) for bilinguals. The bottom is equally and frequently ignored, with only 10% and 9% of first looks for both monolinguals and bilinguals, respectively. Overall, in only 30–50% of cases did participants look at the top zone first.

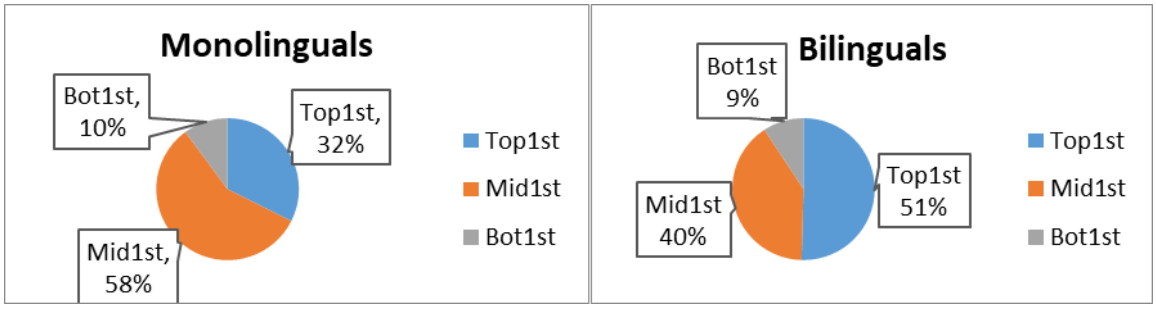


Figure 4 Percentage of First Gazes at All Zones among Monolinguals and Bilinguals

The results also revealed that the strategy employed by monolinguals differs from that adopted by bilinguals. As illustrated in Figure 4, the preferred sequence for monolinguals (English speakers) is MTB–TMB–MBT, whereas bilinguals (Mandarin L2 English speakers) favour the sequence TMB–MTB–MBT. However, they both leave the bottom for last. Looking at the top first only occurred 30–50% of the time among all participants.

Discussion

This study was intended to investigate the impact of knowing one or more writing systems, that is, being monoliterate or biliterate, on the reading strategies employed while reading signs among members of two linguistic groups, English monolinguals and Mandarin EFL speakers. The study used eye-tracking to detect the differences in the reading of signs regarding gaze direction. Differences between the two groups were found in terms of the direction of reading. English monolinguals preferred to read street signs starting from the middle, then move to the top and then move to the bottom (MTB). Chinese bilinguals, on the other hand, preferred to read the signs starting from the top, then move to the middle and then move the bottom (TMB). These preferences were salient across the types of signs used in the study. Thus, although the results show little effect on the part of the L1 on the direction of sign reading, the hypothesis that Mandarin-English bilinguals and English monolinguals would look at the signs differently was not statistically supported by the data of the current study and is thus rejected.

The results of this study can be conceived of as showing little effect on the part of the L1 on reading directionality. Indeed, the different preferences reported in the Results section above can be attributed to the different writing systems used in Mandarin and English. English is an alphabetical language, whereas Chinese uses a logosyllabic writing system. More importantly, text direction in Traditional Chinese may have impacted the data of the current study. Gu (2020) suggests that the vertical text direction used in Traditional Chinese reflects Chinese culture and thought. Huang et al. (2023) also reported that vertical texts are still used now, primarily for artistic and aesthetic purposes. Thus, the Chinese bilinguals who participated in the current study are used to reading vertical texts in their L1 in the TMB direction. English monolinguals, on the other hand, may be attracted to larger and catchier text first, which is typically placed in the middle of a street sign. This could explain their preference for the MTB direction. The finding that text size did not have a significant influence on reading direction challenges the findings of Hsiao et al. (2019), who reported that Mandarin speakers' first fixations were influenced by the factor *text size*.

Despite that the differences found between the two groups in the current study are not significant, the findings can still provide some evidence in favour of the studies

reported above that claimed a Whorfian effect on Mandarin (Bloom, 1981; Boroditsky, 2001; Furhman et al., 2011; Kuo and Sera, 2009; Zhang and Schmitt, 1998). The findings also confirm the Whorfian effect during the reading of texts, which has been found in studies conducted in other languages, such as Arabic, specifically Mashat's (2017) comparative account of the impact of text direction on first fixations in Arabic and English speakers. It should be noted that although Mandarin speakers are more used to vertical texts that are read from top to bottom, they still find horizontal texts easier to read and have also been reported to better memorise the content of horizontal texts (Huang et al., 2023; Sun et al., 1985). Also note that horizontal texts are not free from challenges for Chinese readers. Cui (2023) reported that eye-tracking experiments have revealed that the optional spacing in horizontal Chinese texts hampers readers' fluency. Cui's (2023) findings are in line with Blythe et al. (2012), who reported that spaces between Chinese characters helped Chinese second-language speakers learn new words quickly.

The findings of this study have numerous implications, especially for advertisers. Because there are noticeable but statistically insignificant differences between readers speaking different L1s in terms of the first area they focus on in street signs written vertically, advertisers can anticipate the first line readers of a given L1 will focus on. Thus, important information in an advertisement or a street noticeboard can be placed according to the audience targeted by the text. This is especially important because most drivers and other street/highway users do not have sufficient time to read the entire text in a sign. This can perhaps explain why readers of street advertisements are first attracted by the visual aspects of a sign, rather than the text, which can be time consuming to read (Cui et al., 2023). Another implication for advertisement designers and landscape planners is that readers from both linguistic groups are not likely to read texts starting from the bottom. Thus, written advertisements targeting English or Mandarin native speakers are not advised to place important information at the bottom of a sign.

The results of this study also have educational implications, especially for developers of educational websites targeting various linguistic groups. Anticipating the lines that learners will start reading from in announcements posted on websites would maximise teachers' and educational websites developers' potential to successfully grab

readers' attention by placing important information in areas that are expected to attract readers' attention first. When displaying information vertically, for example, important information should be placed on the top line when targeting Mandarin speakers, whereas texts targeting native English speakers may place important information in the middle of a vertical short text.

Conclusion

This study aimed at investigating the impact of an individual's L1 on reading English vertical signs using an eye-tracking experiment. Twenty-seven participants belonging to two linguistic groups, English monolinguals and Chinese EFL speakers, were randomly selected to participate in this study. The data showed different behaviours across the two linguistic groups, with English monolinguals favouring the order MTB and Mandarin speakers typically read signs from top to bottom (i.e., TMB). The difference between the two groups, however, was not statistically significant.

Although careful measures were taken to control the sample, there were some limitations that could not be overcome. For example, the impact of exposure to text written in languages other than English in the English monolinguals group was difficult, if not impossible, to avoid. English monolinguals are expected to be exposed to texts in other languages in the city landscape, Chinese restaurants' menus and overseas travels. None of the English monolinguals reported familiarity with the Chinese writing system, but the impact of even limited exposure to Chinese texts cannot be rejected without evidence. Additionally, despite the authors' efforts to recruit as many participants as they could, recruitment of participants was subject to the willingness of the study population to participate in the study. This has led to the inclusion of a relatively small number of participants in the current study. Therefore, the authors recommend the inclusion of more participants informed by a priori power analysis.

Future studies are recommended to recruit more participants and investigate the potential impact of font size and type on the direction in which vertical texts are read. Text features (e.g., bold, italics and underlining) may also impact the direction of reading for such texts. Another area worth investigating is the impact of text genre (e.g., menu, noticeboard or advertisement) on the order of reading for short texts. Future studies are also

recommended to account for multilingualism as a factor potentially controlling participants' cognitive control (see Bialystok & Craik, 2022, Costa et al., 2008; Privitera et al., 2022; Privitera et al., 2023).

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