Title

Effects of text space of Chinese-English bilingual traffic sign on driver reading performance

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Author Biographies

Yuchan Zhang is a third-year PhD researcher in the Department of Typography & Graphic Communication at University of Reading. She earned her master's degree in graphic communication design from the school of design at Jiangnan University of China in 2017. Her research interests lie in signage design and bilingual typography. Her research investigates how changing typographic presentation can improve the legibility of bilingual traffic signs, and how its impact on driver's effective reading, understanding, and action of bilingual traffic information.

ABSTRACT

Chinese-English bilingual traffic signs (CEBTS) are widely applied in public spaces within China, but few studies have addressed the spatial arrangement of the two languages on CEBTS and road standards provide little guidance for it. This study investigates whether changes in 'separating space', the vertical space between bilingual place names on CEBTS, affects driver reading performance. Ten sign combinations were developed using variations in the sign's graphic complexity, total number of place names, and the spatial distribution of the place names. Each sign was displayed in a 3D graphics rendered clip of someone driving towards the road sign in random order. Participants identified destinations by reading the signs shown in the clip. The speed and the accuracy of responses was recorded. 39 English-reader participants were recruited and equally split into three groups. Three levels of separating space 0.5H, 0.75H and 1H; H refers to one Chinese character height, were prepared according to a between-subject factorial design. The results show that the separating space affected the response time regardless of sign combinations. Both 0.5H and 0.75H separations caused significant faster reading time and higher accuracy than 1H, but 0.75H appears to achieve better result. The findings contribute to the legibility research concerning bilingual signs with two very different character sets. This study considers improving sign legibility through spatial arrangement of the bilingual text, which is currently limited in the field of Chinese road sign legibility. The findings could inform future standards for Chinese-English road signs.

Keywords: driver reading performance, bilingual traffic sign, sign layout design, bilingual typography

1. Introduction

In increasingly multicultural Chinese cities, Beijing and Shanghai for example, bilingual signs depicting information in both Chinese and English are widely applied in public areas. Although bilingual traffic signs have been used in China for decades, their design has changed little and, in many cases, the two languages do not work together coherently. Noticeable ambiguities and inconsistencies in current practice can be observed (see Figure 1), which may reduce sign efficiency and therefore could ultimately have an impact on user performance and safety.

Figure 1. Bilingual traffic signs photographed in Beijing and Shanghai in 2018. The text and graphic presentation in the two examples differ, note details such as the shape and style of the arrow, the spatial relationship between place names and the use and positions of other graphic elements. Additionally, although published standards cover the usage of both Chinese and Latin scripts, there is still misuse and misunderstanding of the guidance in practical application. For example, condensing of English letters, inconsistent word and letter spacing in the English text, and inconsistent typeface and type size in the Chinese text.

The current inconsistencies in the design of traffic signs in China might be a result of the lack of visual specifications in Chinese traffic sign standards to support designers' decision-making. Review of existing standards, such as *GB5768-Road Traffic Signs and Markings: Road traffic signs* [1] and *JTCD82-Specification for Layout of Highway Traffic Signs and Markings* [2] indicate that there are visual guidelines that relate to typeface and size for the bilingual texts. However, the specification does not sufficiently consider the spatial arrangement of bilingual texts. This may be because few studies specifically address the role of sign layout in traffic signs, especially for bilingual signs.

Sign layout relates to arrange the two-dimensional graphic elements, such as textual message, symbol, and arrow into formats [3]. Regarding to textual message, sign layout relates to how the text space, such as letter space, word space, and line space is arranged to assist legibility [4].

Anderton, Johnston [5] and Cole [6] concern monolingual English signs, claiming the spacing of letters is not a significant factor in sign legibility and can be regarded as an aesthetic consideration. Nevertheless, Solomon [7] believes that the letter spacing used in highway signs affects the sign legibility at night. Lay [8] proposes that an appropriate letter spacing, about 0.3 times letter height, achieves better legibility. The previous studies provide conflicting results and Tejero, Insa [9] believe this is because none of these studies required the participants to drive while reading the signs. Thus, Tejero et al. used a driving simulator to test the effect of interletter spacing on reading traffic signs and they provide evidence to support that drivers can benefit from increasing the default interletter spacing of words. Apart from the letter spacing, Garvey and Kuhn [10] also mention that line spacing of 75 percent of the capital letter height appears optimal for legibility. However, little research has considered the effect of spacing for bilingual signs as a variable of interest.

Rutley [11] published *An Investigation into Bilingual (Welsh/English) Traffic Signs* that was one of the first scholarly discussions of the design for bilingual traffic signs. Research on bilingual traffic signs has confirmed that more reading time is required than on unilingual signs, and two methods could be applied to minimise the reading time: sequencing the languages and demarcating the two languages [12-15]. Research in the field of displaying bilingual text has also been carried out on variable message signs [16-19].

But these studies all focus on bilingual traffic signs where the two languages use the same alphabet (although the combinations of letters are different) and the results might not be sufficiently applicable to CEBTS where the character sets are very different. Because the differences in the languages aid the users to locate the text they need quickly [20], sequencing and demarcating the two languages may not be the main concern any more. A study argues that the ineffective English information on CEBTS is due to the small letter size and inappropriate translation [21]. However, there has been little work investigating whether this ineffectiveness in relation to the inappropriate spatial presentation of the two scripts.

Thus, this current study examines whether reading times for CEBTS can be reduced by changing the spatial arrangement of the Chinese-English bilingual text. The study aims to address the above question using a simulation which displays a number of CEBTS with varying text spacing. The novelty of this study is thus (a) considering road signs combining two writing systems with very different glyph anatomies; (b) considering improving reading speed through spatial arrangement of the bilingual text, which is currently limited in Chinese road sign legibility research.

Specifically, this study attempts to determine whether the *separating spacing*, the vertical space between two bilingual place names on CEBTS (see Figure 2), affects name identification or reading times and, if it has an impact, recommend how large separating spacing should be.

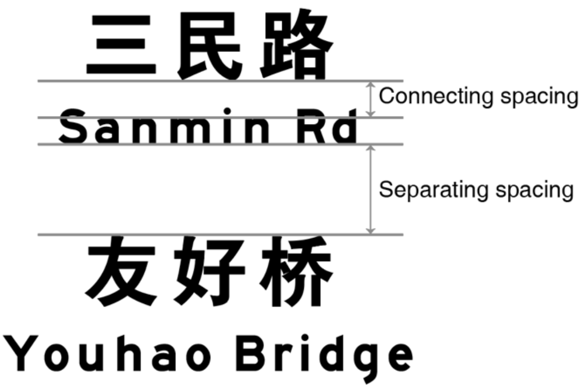

Figure 2. Connecting spacing between Chinese and English text and separating spacing of two bilingual place names. Connecting spacing is 'line spacing' between the two languages and separating spacing is 'line spacing' that separates two different place names.

In the field of typography, the term line spacing, or leading, is used to describe the vertical distance between two lines of text. When Chinese and English are combined into two lines of bilingual text, studies on how to deal with the line spacing to benefit both Chinese and English readers are scarce. Nevertheless, the existing studies of the effect of line spacing on response time in both Chinese and English have primarily focused on continuous reading. Regarding English reading, line spacing means the distance between baselines and it is usually considered along with type size and line length. Hochuli [22] suggests that the larger the type and the longer the line, the more line spacing is needed. Luna [23] and Highsmith [24] recommend adding 20 percent to the type size to give the line spacing for the standard practice on text setting. When doing a visual search on a web page, Ling and van Schaik [25] found that deeper line spacing achieved faster search time. However, for Chinese reading, Chan and Steve [26] found that the increased line spacing resulted in longer reading time in proofreading performance.

Before any experimental investigations, samples of signs in situ were collected so that what is commonly used in real practice could be identified and therefore, the appropriate levels of vertical spacing and sign complexity to test could be identified. In this present study, the connecting spacing (see Figure 2) was set at half Chinese character height and kept consistent[1]. To understand whether the findings of this study can be applied to a range of signs and find out if a generalisable separating spacing can be applied across sign categories, sign complexity (see Section 2.1) was taken into account as one of the variables.

Separating spacing is required only on signs with two or more place names arranged vertically. The number of place names relates to the amount of information, which is particularly important to consider due to many studies suggesting that reaction time increases according to the information quantity on both English [27-29] and Chinese traffic signs [21, 30, 31]. Thus, it seems appropriate to also determine whether the impact of separating spacing varies according to the total number of place names on a sign ('total number' will be used for simplicity from here on).

[1] This current study builds upon the methodology and findings from the writer's previous work [unpublished study carried out as part of PhD thesis that to be submitted in 2021]. It investigated the effect of changes in connecting spacing, the vertical spacing between Chinese and English text of a bilingual place name (see Figure 2) on the traffic sign legibility. In that study, four levels of connecting spacing were evaluated under two sign complexities (the appropriate levels of connecting spacing and sign complexity to test were identified by observing the sign samples collected in practice). Each condition was displayed in a 3D graphics rendered clip of driving towards the sample road sign(s) in random order (this method was also applied to the current study, see details in section 2). The results of the previous study suggested that the connecting spacing of a half Chinese character height, compared to greater or smaller depth connecting spacing, improved the speed of reading CEBTS, and the impact of connecting spacing differed according to sign complexity.

Additionally, on a sign that indicates two or three directions, it is also important to determine the number of place names per direction (will use ‘direction number’ from here on) as this number can vary. This creates many different combinations of total place names across two or three directions (see Figure 3). Thus, if the separating spacing has an impact on driver performance, it would be better to know whether this impact may vary for the different arrangements of place names and directions.

Figure 3. Three directional signs with various total number of place names. The three signs all indicate three directions but presenting three (left), four (middle) and five (right) place names with different number of name (s) per direction. Photographed in Shanghai (left and middle) and Dalian (right), China, in 2018.

In summary, the intentions of this study are to examine:

1. whether separating spacing has an impact on driver ability to read destination names;
2. if it has an impact, to recommend how large separating spacing should be;
3. whether the separating spacing changes according to sign complexity, the total number, and the distribution of the direction number.

2. Method

2.1. Determining combination possibilities

Sign complexity, the total number, and the direction number are interrelated and cannot be considered in isolation. There are many different combination possibilities in practice (see Figure 3) so it seems appropriate to map out how many possibilities in order to determine how many exposures each participant will get.

Sign complexity can be grouped simply into three levels in terms of number of directions shown (see Figure 4). The three levels can cover a range of sign categories used for urban routes in China. In Table 1, all variations of the total number under the three sign complexities are summarised.

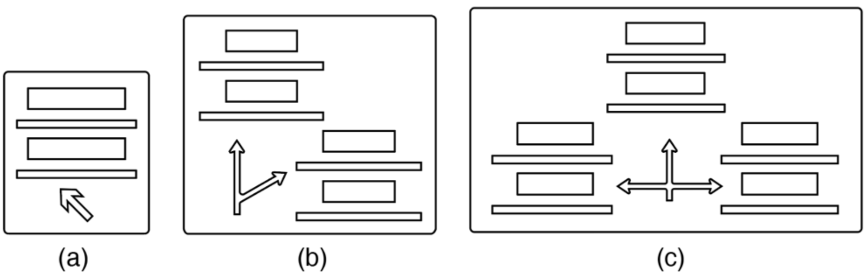

Figure 4. Three levels of sign complexity. (a) one-direction sign; (b) two-direction sign; (c) three-direction sign.

TABLE 1: The variations of total number under three levels of sign complexity.

Sign complexity	Max total no.	Min total no.	Variations tested
(a)	3 (4 is rarely use)	1	**2, 3**
(b)	4	2	**3, 4**
(c)	6	3	**4, 5, 6**

Total number was determined by observing photographed sign samples and the relevant specifications in published standards.

On a one-direction sign, there seems no guidelines in the relevant standards providing the maximum numbers of place names on it. Instead, collected sign photographs were observed and they indicated that the maximum number commonly used is 3 names (see Figure 5). Thus, two variations (2 names and 3 names) were evaluated.

Figure 5. One-direction sign with three place names. Photographed in Dalian, China in 2018.

According to the standard *GB 51038-2015 Code for layout of urban road traffic signs and markings*[32], on a two-direction and three-direction sign, the maximum number of place names within one direction is 2, and 6 in a single traffic sign. Accordingly, the maximum total number on a two-direction sign is 4 (2 directions × 2 place names) and is 6 on a three-direction sign (3 directions × 2 place names). Excluding the minimum total number (because the separating spacing only exists when there are at least two place names per direction), the variations considered were 3 and 4 place names on a two-direction sign, and 4, 5, and 6 place names on a three-direction sign.

Once the variations of the total number on the sign were confirmed, the next step was to consider the direction number. Figure 6 and Table 2 illustrate all 10 combination possibilities of the total number and direction number across three sign complexities. The term ‘combination’ will be used to refer to an association that joined sign complexity, the total number and direction number.

As Figure 6 and Table 2 show, combinations B1, B2, B3, C1, and C4 have two similar versions that only differ in the number of place names within the right or left direction. Since the two versions are symmetric figures, the findings might work on both. To streamline the experimental design (too many multiple factors in turn will elevate the complexity for the statistical analysis), only the version with 2 place names in the right-hand direction was tested.

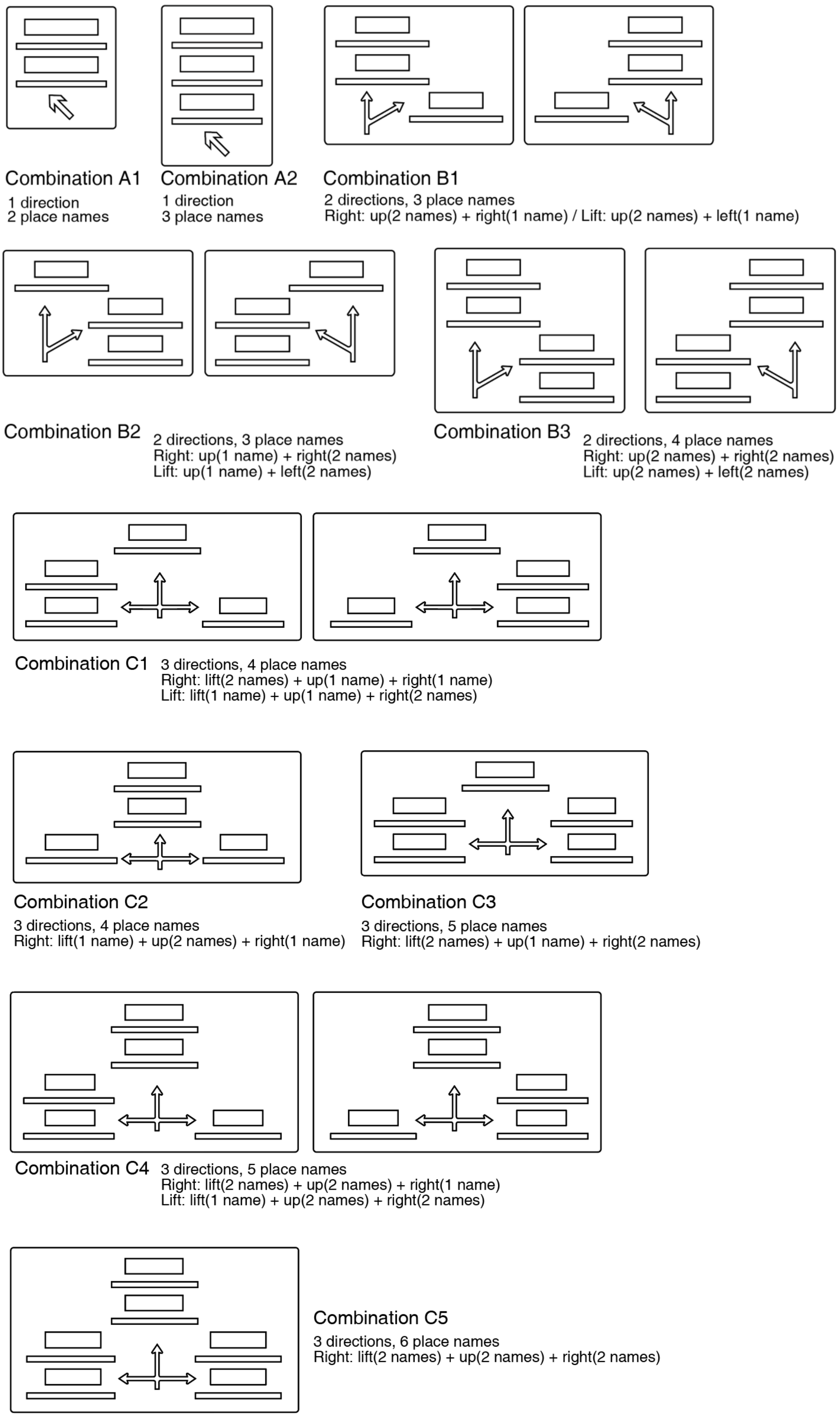

Figure 6. Mapping out all possible combinations of total number and direction number across three sign complexities and excluding the simplest combinations, as per Table 1.

TABLE 2: All combinations of total number and direction number crossing three sign complexities.

	Number of directions (Sign complexity)	Total number	Direction number		
			Left	up	right
Combination A1	1	2	all place names within one direction		
Combination A2	1	3			
Combination B1	2	3	×	2	1
			1	2	×
Combination B2	2	3	×	1	2
			2	1	×
Combination B3	2	4	×	2	2
			2	2	×
Combination C1	3	4	2	1	1
			1	1	2
Combination C2	3	4	1	2	1
Combination C3	3	5	2	1	2
Combination C4	3	5	2	2	1
			1	2	2
Combination C5	3	6	2	2	2

2.2. Selecting separating spacing levels

Separating spacing, as introduced above, is the vertical space used to separate two bilingual place names within one direction. This is to distinguish it from *directional spacing* that refers to the vertical space between two place names that signal different directions (highlighted in Figure 7). As it is uncertain if there is an interaction between the separating spacing and directional spacing, the directional spacing was consistent with the separating spacing used in all stimuli in order to isolate findings that may be affected by this factor.

Figure 7. Separating spacing and directional spacing on a three-direction sign. Photographed in Shanghai in 2018.

According to Gibson's [33] suggestion for monolingual English signs, on a sign where texts are in a narrow column, 'two-line names are tightly line spaced while the spaces between names are just generous enough to differentiate entries…'. In this case, the separating spacing should be set larger than connecting spacing to differentiate bilingual place names. Because the previous study informs a recommendation of connecting spacing of half the height of the Chinese characters (see footnote1), this was selected as the separating spacing to be tested. According to the samples collected, most separating spacing used on the sign is in the range from 0.5H to 1H (H refers to the height of one Chinese character height from here on). Then, the middle-value 0.75H was also selected to be evaluated. In summary, three levels of separating spacing were tested: 0.5H 0.75H and 1H.

Line length of continuous Latin text has been identified to affect reading performance [34, 35]. Since, it is uncertain if there is an interaction between the separating spacing and the length of English on a bilingual sign, the length of English place name was kept consistent (12 letters) to isolate findings possibly affected by this factor. The way that the bilingual texts should be aligned has not yet been established, i.e. horizontal arrangement on the line of display. Typically, in signs observed, alignment is central. Although this may not be optimal for legibility, all the texts used in the study were centrally aligned.

2.3. Material design

To enable efficient testing of a multiple stimuli, in this study, participants read from a monitor displaying video clips of the stimuli enlarged gradually, similarly to when driving, the sign expands as the driver approaches the sign; the height of the visual horizon in the clips was set to 1.2 meters above the lane based on the actual average height of a person sitting in a car [36]; and the height of the sign was set based on its actual height in use, similar to the driver's angle of view when reading a sign. Participants were primed to search for a place name among a set of names, similar to drivers looking for a destination on a sign encountered along the route. Participants were asked to respond by indicating the direction they needed to take (e.g. left, right, ahead) on a keypad once they had identified the target place name, similar to the driver acting on the sign. These efforts were made to simulate driving activities and ensure the scenario was reasonably realistic in order to gain reliable results.

To simulate the actual driving experiences in China, the design of the stimuli and the clips were all based on the related regulations [1, 32]. These covered typeface and size specifications for example, graphic elements guidance such as arrows and borders, as well as the spatial value such as the distance between text and graphic elements used on the stimuli. The lane width was 3.5m and posted speed limit was 40 km/h. The location, size, height, and construction of signs also followed the standards. In each clip, the car was driven on the right side of the road, having the steering wheel on the left side. For testing, two versions of video clips were developed for one-direction sign and two-and three-direction signs respectively (see Figure 8) and the two versions that are the two most commonly used sign mounted methods in China, overhead sign and shoulder-mounted sign.

Figure 8. Screenshots of the video clip developed for the two-and three-direction sign (top) and the one developed for a one-direction sign (bottom).

Additionally, using a monitor displaying clips showing someone driving towards traffic road signs sufficiently controlled the variables across the study, which ensured all separating spacing variants were compared under equivalent conditions. All stimuli were drawn in Adobe Illustrator 2019 and the video clips were 3D graphics rendered in Lumion. There were no passing vehicles, lane changes and slowdowns in the video clips, so as not to distract participants reading the sign. All contextual parameters were kept consistent.

The duration of the video clips was limited to prevent participants from prioritising accuracy over speed. A pilot study was conducted to determine the duration of clips. The pilot session recruited 6 participants, each receiving 10 trials that covered all combinations and levels of separating spacing. Each participant took around 5 minutes to complete the pilot. Based on the average response time of 6 participants to the 10 combination trials, each clip was displayed in the main study for up to 7 seconds with presentation terminating before the full 7 seconds, once the participant responded.

2.4. Equipment and site

A 75-in monitor at a resolution of 1280×1024 pixels was used to display video clips. A personal laptop ran E-Prime 2.0 software that controlled the timing, presented the stimuli, and recorded data in a spreadsheet.

The participants sat behind a 0.8 m-height table which was 1.6m away from the monitor (these two values were identified in the pilot study). An adjustable chair was provided for the participants to be comfortable throughout the test. A computer keyboard, adjusted to provide three directional arrows for participants to respond, was provided on the table.

Both the pilot and main study were carried out in the same room at a campus location.

2.5. Participants

The participants were students and staff recruited from the campus and were recruited with screening questions: a. have normal or corrected vision; b. have driving license; c. between ages 24 to 50 years old; and d. do not read Chinese and use English as first or second language. Because eyesight, driving experience, and age affect driver on reading road signs [37-39], the screening questions a. to c. were used to isolate the result that may be affected by these factors. Hulbert and Beers [40] found the highest comprehension level is achieved by drivers aged 24 to 50 years old, therefore, this age range was selected.

The users of CEBTS vary by language ability because they need assistance from the information written in their tongue. The users of CEBTS could be divided into three groups based on their language background: Chinese drivers, bilingual drivers who can read both Chinese and English, and foreign drivers who cannot read Chinese and only rely on the English information. In this study, only foreign drivers were tested, and the other two groups were screened out. That was because the very different appearances of the two languages and the much larger type size of the Chinese text aid Chinese and bilingual drivers to locate the Chinese information faster [20, 21]. Thus, the vertical spacing would have less of an impact on these two groups. Yang, Chen [21] declare that bilingual drivers prefer to read Chinese information because they feel that the English information is difficult to read, and Yang et al. suggest increasing the letter size to improve sign legibility. However, considering the limited space of a sign surface, this study aims to explore how to deal with the vertical spacing of the bilingual text to benefit the foreign drivers to read CEBTS without increasing the type size.

Participation was entirely voluntary. The study was conducted in compliance with the University's research ethics policy and all participants gave consent to participate.

Finally, 43 participants were recruited in total but 4 were excluded because they did not meet the age requirements. Participants were systematically split into 3 groups, each of 13 participants. Each group received a different ‘separating spacing condition’:

- 0.5H group: participants viewed all signs with 0.5H separation;
- 0.75H group: participants viewed signs that designed with 0.75H separation;
- 1H group: participants viewed signs with 1H separation.

2.6. Procedure

The main study took around 10 minutes per participant. Each participant first completed 5 practice trials, followed by the 10 experimental trials presented in random order.

The participants were cued by the researcher that the task was ready. The importance of responding quickly was emphasised by the researcher before the task. Using the display described in section 2.4, participants were shown several short video clips. For each one, they were asked to answer a question in the form of ‘what direction should be taken to destination xxx?’. The participants were asked to read out the question, which aimed to force them to carefully read the destination and reduce the temptation to skim through the words. After that, the SPACE key allowed the participant to self-pace when they were ready to engage with watching the clip. The participants needed to find the answer by reading the sign they saw in the video. When the participants had identified the direction, they were able to make their response by pressing the direction on the keyboard, which also stopped the video and caused the screen to go to the feedback screen (showing the time taken and accuracy). The participants repeated the same procedure until all stimuli had been displayed.

The block diagram (see Figure 9) shows the relationships between some aspects of the method and the stages the participant goes through.

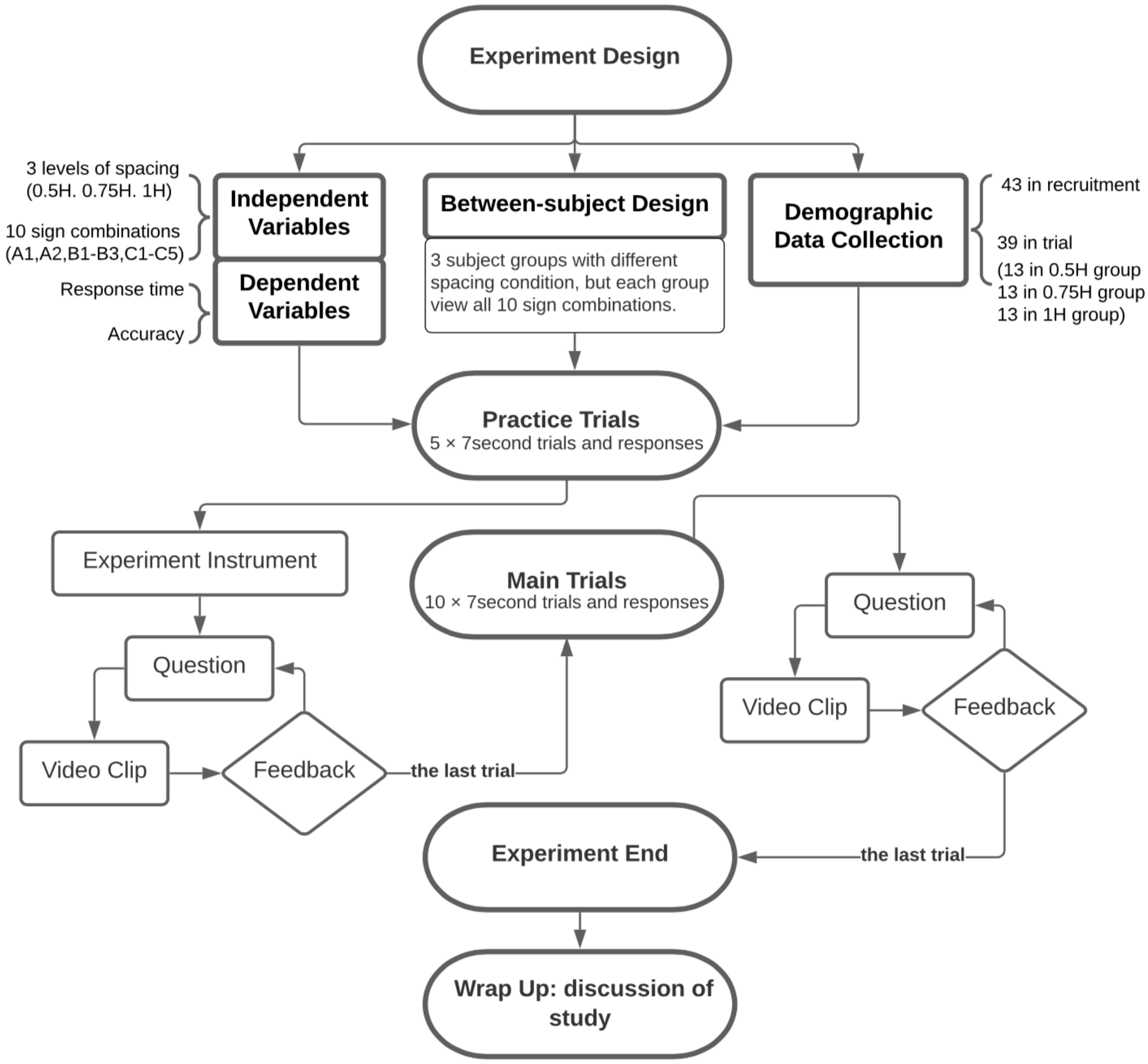

Figure 9. A diagram of the relationships between some aspects of the method used and the stages the participant goes through

3. Result

3.1. Separating spacing and response time

The means of response times for the 0.5H group, 0.75H group and 1H group were 5.026s (SE = .083), 4.934s (SE = .084) and 5.366s (SE = .084) respectively. A two-way ANOVA was used to examine the effects of separating spacing and combination on the time taken in reading CEBTS. There was a main effect of separating spacing $F(2, 335)=7.312$, $p = .001$, partial $\eta 2 = .042$. There was no significant interaction effect between the separating spacing and combinations on the time taken to reading signs, $F(18, 335) = .539$, $p = .938$, partial $\eta 2 = .028$.

All pairwise comparisons were run for 95% confidence intervals and *p*-values were Bonferroni-adjusted (see Table 3). The Sig. column indicates significant differences in response time between 1H and 0.5H separating spacing, and between 1H and 0.75H separating spacing.

TABLE 3: Pairwise Comparisons. The differences in mean "response time" score between separating spacing levels.

Pairwise comparison		MD	Sig.[b]	95% CI
1H	0.5H	.340	.013	.055, .624
	0.75H	.431	.001	.145, .718
0.5H	0.75H	.092	1.000	-.192, .375

The mean difference is significant at the .05 level.
b. Adjustment for multiple comparisons: Bonferroni.

3.2. Separating spacing and accuracy

Accuracy of response for the 0.5H, 0.75H and 1H groups was, respectively, 81.3%, 87.7% and 84.4%. A chi-square test of homogeneity was used between separating spacing groups and the accuracy of response. All expected cell counts were greater than five. There were no significant differences in the percentage of accuracy in three separating-space groups, p = .384.

3.3. Combinations and response time

An analysis of the main effect for combination was performed using a two-way ANOVA, which indicated that the combination affects the speed to response traffic signs significantly, F(9, 335 =6.956, p <.001, partial $\eta 2$ = .157. Given that there was a significant difference in response time between 1H and 0.5H, and between 1H and 0.75H separating spacing, the 'response time' on the data of those individuals that received 0.5H and 0.75H separating spacing exposures was extracted to analyse.

3.3.1. Distribution of the direction number

Difference in response to the spatial distribution of direction number was compared when the sign complexity, and total number was consistent. Accordingly, the response time data of the combination B1 and B2, C1and C2, as well as C3 and C4 were extracted to be compared respectively (see Figure 9). The analysis excluded A1 and A2 because these two combinations are one-direction signs where all place names are distributed within one direction.

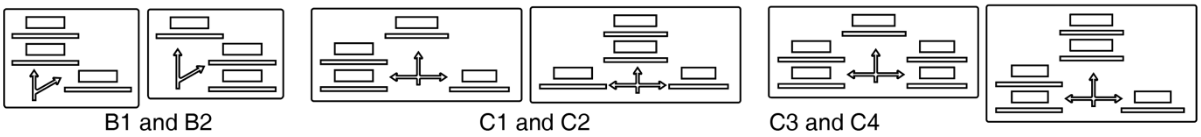

Figure 9. Three pairs of combinations. The two combinations in each pair include same total number and under same sign complexity. But the distribution of the direction number is different.

A paired-samples t-test and a Wilcoxon signed-rank test were conducted. The means of response times for the three pairs of combinations under both 0.5H and 0.75H group were listed in Table 4. In both separation conditions, there was no significant difference between:

B1 and B2 (0.5H: p =.207, 0.75H: p =.330);

C1 and C2 (0.5H: p =.530, 0.75H: p =.880);

C3 and C4 (0.5H: p =.434, 0.75H: p =.157).

TABLE 4: The mean response time for the three pairs of combinations under 0.5H and 0.75H sepaaration.

0.5H	M	SE		M	SE		M	SE
B1	4.522	.262	C1	4.603	.255	C3	5.474	.238
B2	4.835	.259	C2	4.690	.261	C4	5.182	.203
0.75H								
B1	4.376	.339	C1	4.367	.288	C3	4.884	.398
B2	4.888	.413	C2	4.318	.398	C4	5.540	.228

3.3.2. Total number

Difference in response time to the total number of place names was compared when the sign complexity was consistent. One-direction signs were excluded because three one-direction signs were displayed simultaneously in the study which meant that the total number that participants received was more than the other two complexities (6 in A1 and 9 in A2).

In two-direction sign condition (combination B), the mean and std. deviation of response time for the number variations of place names, under both 0.5H and 0.75H separation levels, are listed in Table 5. A one-way repeated ANOVA showed that the changes in the total number did not elicit significant differences in the two separation levels, and Table 6 presents the pairwise comparison among factors:

0.5H: $F(2, 24)$ =1.366, p =.274 partial η^2 = .102;

0.75H: $F(2, 18)$ =.896, p =.426 partial η^2 = .091.

TABLE 5: Mean and Std.Deviation of response time for total number on two-direction signs under 0.5H and 0.75H separating spacing levels.

TWO-DIRECTION SIGN			
0.5H		M	SD
3 place names	B1	4.522	.094
4 place names	B2	4.835	.934
	B3	4.706	1.030
0.75H			
3 place names	B1	4.376	1.015
4 place names	B2	4.888	1.513
	B3	4.922	.763

TABLE 6: Pairwise comparison for total number on two-direction signs under 0.5H and 0.75H separations.

0.5H		MD	Sig.b	95% CI
B1(3 names)	B2 (4 names)	-.312	.620	-.962, .338
	B3 (4 names)	-.183	.494	-.528, .161
B2(4 names)	B3 (4 names)	.129	1.000	-.414, .672
0.75H		MD	Sig.b	95% CI
B1(3 names)	B2 (4 names)	-.512	1.000	-2.178, 1.154
	B3 (4 names)	-.545	.647	-1.746, .655
B2(4 names)	B3 (4 names)	-.034	1.000	-1.112, 1.045

The mean difference is significant at the .05 level.
b. Adjustment for multiple comparisons: Bonferroni.

In three-direction sign condition (combination C), 4 place names (C1 and C2), 5 place names (C3 and C4) and 6 place names (C5) were compared among each other to determine whether there was a significant mean difference in response time. As described above there was no difference in response time between the combination C1 and C2, also between C3 and C4. Accordingly, to help minimise potential confounds, the mean response time of C1 and C2, as well as C3 and C4, was calculated to represent the response time of 4 place names and 5 place names separately.

The mean and std. deviation of response time under both 0.5H and 0.75H separating spacing levels are listed in Table 7. A one-way repeated ANOVA showed that the total number affected the time taken to respond:

0.5H: $F(2, 20) = 5.091$, $p = .016$, partial η2 = .337;

0.75H: $F(2, 24) = 3.846$, $p = .036$ partial $\eta^2 = .243$.

TABLE 7: Mean and Std.Deviation of response time for total number on three-direction sign under 0.5H and 0.75H separating spacing levels.

THREE-DIRECTION SIGN			
0.5H		M	SD
4 names	C1C2(mean)	4.447	.498
5 names	C3C4(mean)	5.301	.458
6 names	C5	5.180	1.052
0.75H			
4 names	C1C2(mean)	4.461	1.108
5 names	C3C4(mean)	5.106	.801
6 names	C5	5.085	.816

Post hoc analysis with a Bonferroni adjustment revealed that, in 0.5H separation condition, response time significantly increased from 4 to 5 place names, but not from 4 to 6 place names and from 5 to 6 place names. However, in 0.75H separation condition, the pairwise comparison did not show a significant difference among the total number variations. Table 8 presents the pairwise comparison among factors on the three-direction sign under 0.5H and 0.75H separation conditions.

TABLE 8: Pairwise comparison under 0.5H and 0.75H separating spacing levels of three-direction sign.

0.5H		MD	Sig.b	95% CI
4 names	5 names	-.855	.006	-1.451, -.258
	6 names	-.733	.093	-1.572, .106
5 names	6 names	.121	1.000	.121, .351
0.75H				
4 names	5 names	-.646	.157	-1.479, .188
	6 names	-.624	.096	-1.340, .092
5 names	6 names	.022	1.000	-.622, .665

Based on estimated marginal means. The mean difference is significant at the .05 level.
b. Adjustment for multiple comparisons: Bonferroni.

3.4. Combinations and Accuracy

Difference in accuracy was compared when the sign complexity was consistent. The analysis also excluded the data of one-direction sign because three one-direction signs were displayed simultaneously in one exposure but only one two- and three-direction sign was displayed in one exposure. This caused the participants to encounter more place names in one-direction sign exposures, which might lead to lower accuracy.

For two-direction signs with 0.5H separating spacing, the accuracy of response for combination B1, B2 and B3 was, respectively, 99.3%, 100% and 100%. It was 100%, 98.7% and 98.5%, respectively, in the condition of 0.75H separating spacing. Cochran's Q test showed that, for both 0.5H and 0.75H separations, there were no significant differences among the three combinations in accuracy rate,

0.5H: $\chi2(2) = 2.000$, $p = .368$;

0.75H: $\chi2(2) = 1.000$, $p = .607$.

For three-direction signs with 0.5H separating spacing, the accuracy of response for combination C1, C2, C3, C4 and C5 was, respectively, 90%, 100%, 75%, 75% and 57.9%. It was 100%, 98.2%, 96.4%, 98.1% and 92.7%, respectively, in the condition of 0.75H separation. Cochran's Q test showed that combinations with 0.5H separating spacing appears to elicit significant differences in accuracy, $\chi2(2) = 11.152$, $p = .025$, and the pairwise comparison indicated that the accuracy was significantly reduced from 100% (combination C2) to 57.9% (C5), $p = .018$. However, combinations with 0.75H separating spacing had no significant impact on the accuracy, $\chi2(2) = 5.000$, $p = .287$.

4. Discussion

4.1. Selection of separating spacing

This study concerned the vertical space between Chinese and English text on traffic signs. The results showed that the separating spacing affected the speed in reading CEBTS and this effect appeared not to vary according to combination (combination refers to a combination of sign complexity, the total number on a sign, and direction number). Compared to the highest separating space (1H), both the lowest (0.5H) and medium (0.75H) separating spacing resulted in faster response time. However, the medium response time appeared to be faster and had higher accuracy than the 0.5H group, but these differences were not significant. This result was in agreement with Gibson's [33] suggestion that the space that combines two related items should be less than the space that separates them from other items. The less separating spacing (0.5H and 0.75H compared with 1H separating spacing) needed for Chinese-English place names could be explained by the fact that Chinese characters are formed within a square box without ascenders and descenders, and also without diacritical marks or vowel signs above and below characters. This saves the vertical space that should be added in Latin contexts to prevent the crowding caused by ascending and descending characters, and any accent marks [41].

4.2. Sign combination

The main concern of this study was to determine whether the separating spacing, rather than combination, affects the legibility of CEBTS. The result shows that the impact of separating spacing appears not to be linked to the combination, but it is still worth presenting how sign combinations affect the speed and accuracy in driver reading performance which may warrant further consideration for future studies.

The analysis of the combinations shows that, when sign complexity and total number was consistent, in both 0.5H and 0.75H separation conditions, the spatial distribution of the direction number did not affect the speed in reading two-and three-direction signs.

The difference in response time to the total number was compared when the sign complexity was consistent. The result showed that increased response times according to increase in number of place names, though some differences, were not significant. This result was in agreement with the previous research suggesting that the reaction time increases with the information quantity on traffic signs [27-31].

For a two-direction sign, the results also showed that, in both 0.5H and 0.75H separating spacing conditions, the variations of total number (approximately 6 to 8 Latin words) did not elicit significant differences in both response of time and accuracy. This result was consistent with the sign-reading speed research for monolingual English signs indicating that signs with 4 to 8 words could be comfortably read and comprehended [10].

However, the results also showed that, on a three-direction sign with 0.5H separating spacing conditions, the variation of the total number appears to affect the response time significantly. 5 place names achieved faster response time than 4 place names. This is a surprising result that goes against the expected trend and may reflect the small number of data points. However, this difference was not significant with 0.75H separating spacing. Regarding accuracy rate, on a three-direction sign with 0.5H separating spacing, the accuracy rate was significantly reduced from 4 place names to 6. But, again, this difference was not significant for applying 0.75H separating spacing. Additionally, the mean accuracy rate of a three-direction sign with 0.75H separating spacing was 97.08%, which was higher than that with 0.5H separating spacing (79.58%).

In summary, the results may indicate that, in contrast with 0.5H, 0.75H is a generalisable separating spacing that may be able to perform well, in both response time and accuracy, across number variations of place name.

4.3. Contributions and Limitations

In an ideal world, it might be argued that signs should be tested in situ and in real settings whilst driving. However, Waller [42, p3] suggests that "this would be impracticable for several reasons, including the high cost of mounting signs with multiple factors in turn, and the difficulty in obtaining judgements in consistent conditions". Accordingly, this study used a 3D rendered animation to simulate driving context and experiences in China. This was done to ensure the variables were sufficiently controlled across the study and all variants were compared under equal conditions. Additionally, without the stress of driving, the participants only needed to view clips and press the keyboard which ensured their safety whilst performing the tasks. However, drivers must do other tasks in parallel to driving, such as controlling the vehicle and interacting with other vehicles [43]. Thereby, many researchers use a fully interactive driving simulator [9, 16, 21, 37] to test traffic signs by allowing participants to control a vehicle at the same time yet guaranteeing safety. However, to access the state-of-the-art facilities in driving simulation centres is an expensive process and such a professional simulation centre is limited around the world[2].

The findings of this study verify the importance of text spacing in Chinese-English bilingual traffic signs and could inform the spatial arrangement of the bilingual information combining with two very different character sets on a road sign. The results may indicate that the vertical spacing that separates bilingual place names should be wider than the spacing that combines the two languages to

[2] There are state-of-the-art facilities (driving simulator) existing around the world,
In England: Institute for Transport Studies, University of Leeds (http://www.its.leeds.ac.uk/); Transport Research Laboratory (http://www.trl.co.uk/);
In France: INRETS (http://www.inrets.fr/index.e.html);
In North America: many excellent laboratories, one of which is the University of Michigan Transportation Research Institute (https://umtri.umich.edu/home-page/driving-simulator/);
In Australia: Monash University Accident Research Centre (https://www.monash.edu/muarc).

a bilingual place name. However, Chinese-English place names may need less separating spacing than it needed for monolingual Latin contexts.

Furthermore, considering most of the effort has been focused on typeface design for Chinese road sign legibility [44-46], this study provides a way to optimise sign legibility in relation to sign layout. It may also be possible to use the findings and approach of this study as the first stage in studying other aspects (in relation to sign layout) of CEBTS, for example, by determining the optimal vertical spacing and putting it in control, the effect of the alignment of the bilingual location names and the spatial relationship between them to other pictorial elements (e.g., arrow and symbol), which are also important in reading performance, could be examined.

Several limitations should be noted. The sample consisted adults between 24 and 50. It remains to be determined whether the impact of separating space on bilingual sign here is more or less apparent in younger or older individuals. Most participants were designers or typographers recruited from the school of design. Their expertise may contribute to the recognition of scripts and reduce their response time [47]. Nevertheless, all participants were English readers that prevented the results being affected by their Chinese knowledge.

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