

## Article

# Experimental Study on the Universal Design of Signage Size and Brightness Contrast for Low Vision Individuals

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**Abstract:** Signage is an important medium for individuals to obtain spatial environmental information conveniently and accurately. However, most previous studies focus on signage design for individuals with normal vision, neglecting the specific requirements of those with low vision. Therefore, these signage designs lacking universality restrict the activities of individuals with low vision in public spaces and increase their risks. This study aims to conduct quantitative research on signage size and brightness contrast for low vision individuals. A virtual simulation experimental platform investigated how individuals interpret and react to signage. Two sets of experiments were carried out in Tianjin Key Laboratory of Healthy Habitat and Smart Technology to evaluate the effects of signage size and brightness contrast on response time and accuracy among a total of 139 participants. The results showed that the signage size should be at least 7% of the reading distance to meet the wayfinding needs of low vision individuals. The impact of contrast on wayfinding was strongly dependent on signage size. This research provides valuable insights into the design of signage for low vision individuals.

**Keywords:** brightness contrast; low vision individuals; signage size; universal design



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## 1. Introduction

Signage is an abstract symbol delivering spatial orientation and environmental information through text and graphics. The functional and safety-related information about space and other aspects obtained from signage facilitates wayfinding activities in everyday life [1]. The proportion of people with low vision significantly increases with age [2], and those individuals are at a disadvantage in spatial recognition. “Low vision” is defined as one or several impairments to the normal function of the eye or visual nervous system. The concept of low vision was introduced by Eleanor Faye and Gerald Fonda in 1950 [3]. Scientists who focused on visual impairments during the same period emphasized the importance of residual vision and the need to address limitations in visual function [4,5].

Thus, a clear and effective signage system should be introduced to help low vision individuals to integrate into society freely and independently, thereby improving the accessibility and utilization of the spatial environment [6,7]. In the 1990s, the concept of “universal design” was introduced to the field of architectural design, and visual accessibility was defined as the efficient and safe use of vision to navigate through the environment, perceive key features of the spatial layout, and track position and orientation in the environment [8]. In 1989, Rubin conducted a series of experiments and demonstrated a strong correlation between the contrast of visual objects and low vision reading [9]. In

1992, Arthur proposed that signage is an information vector that clarifies spatial orientation through sequence, numbering, and area marking, enabling the understanding of functional and safety information about space [1]. The guideline ‘Lighting and the Visual Environment for Senior Living (ANSI/IES RP-28-16)’ [10] is one of the earliest guidelines focusing on how visual impairment affects people’s perception of the environment. Then, in 2010, Schambureck et al. used typology of environmental scenarios to address low vision-related issues [11].

In recent years, new technologies for information acquisition for individuals with visual impairments have been developed [12]. In 2006, Walker and Lindsay proposed the use of virtual auditory displays for navigation and localization [13]. Wilson et al. designed a wearable audio navigation system [14]. Legge et al. suggested that “visually impaired individuals use digital signage systems for indoor navigation” [15]. Zhang [16] proposed an intelligent icon design platform; however, this platform only considers the color schemes without considering the size of the icons. Thus, the provided intelligent color schemes still do not meet environmental design needs. Although scholars have made great efforts to develop new technologies to provide equivalent information for individuals with visual impairments, almost all of them focus on utilizing non-visual media to compensate the impaired vision for spatial activities, with little research exploring how to exploit the residual vision [17]. In the foreseeable future, signage remains necessary for the general public and low vision population to capture spatial information for participating in independent activities. Poorly designed spatial signage can reduce users’ recognition of the space, affect their wayfinding activities within the space, and, in severe cases, lead to injuries.

Thus, signage size and brightness contrast are taken as the main variables in this research to study universal signage design for low vision individuals. The brightness contrast is crucial for recognition of signage by low vision individuals. It has been widely recognized that a higher level of brightness contrast between an object and its surrounding environment enables low vision individuals to utilize their residual vision more effectively [6,17–20], thereby improving their ability to recognize signage [9,21,22]. In some countries, using black-white or white-black combinations for signage has even been recommended, emphasizing the importance of maximizing contrast for conveying information.

A common contrast ratio recommendation is 70% for color combinations between foreground and background [22–26]. However, quantitative research on brightness contrast is limited, and there is a lack of both a reliable theoretical framework and empirical evidence [10]. The calculation methods for contrast differ among countries, with the UK and US using Weber’s formula:

$$C = \frac{B_1 - B_2}{B_1 \times 100} \quad (1)$$

where  $C$  is the brightness contrast,  $B_1$  is the light reflectance value (LRV) of the brighter area, and  $B_2$  is the LRV of the darker area. Germany and Spain use Michelson’s formula:

$$C(\%) = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \quad (2)$$

where  $L_{max}$  is the brightness of the brightest color, and  $L_{min}$  is the brightness of the darkest color. The standard Australian signage formula is expressed as follows:

$$C = \frac{125(Y_{max} - Y_{min})}{25 + Y_{max} + Y_{min}} \quad (3)$$

where  $Y$  is the luminous reflectivity.

In subjective evaluation experiments, although brightness contrast or luminous reflectance is often used as the main indicator, there is still controversy over the results. Various studies have shown different minimum requirements of brightness contrast for effective recognition of signage by individuals with low vision. For example, the Japanese

researcher Hayanouchi claimed that the brightness contrast should be greater than 60% for designing the color schemes of tactile paths [27]. A study by the Georgia Institute of Technology in 1985 found that the minimum brightness contrast for effective recognition of signage by low vision individuals should be 70% [26], which was later included in the ADA (Americans with Disabilities Act) Accessibility Guidelines. Yoshida [28] showed that elderly adults required a minimum contrast ratio of 33–50%. Lomperski [29] found through empirical research that the recommended minimum brightness contrast of 70% was significantly higher than the appropriate value. The study of Bright et al. [30] on architectural interfaces in the UK proposed a minimum brightness contrast of 30%.

Although many scholars have recognized the importance of brightness contrast in signage design, there is no consensus on the optimal level, and existing research on brightness contrast in signage design varies widely in terms of both design standards and calculation methods [31]. Table 1 summarizes the lightness contrast requirements for signage in different countries. Moreover, the diverse types of visual impairment necessitate different design requirements for different groups of low vision individuals [32]. In this study, we focus on adjusting brightness contrast to better ensure the independent activity of individuals with low vision.

**Table 1.** Requirements for brightness contrast of signages in different countries [21,33–36].

Standard	The Requirements for Brightness Contrast
Germany	Appropriate combinations are characterized by one or more of the following: high brightness contrast, achromatic components, and combinations of complementary colors. Among them, $<0.16$ is low contrast, $<0.64$ is medium, and $\geq 0.64$ is high contrast; for the visually impaired, the contrast should be more than 0.83.
Spain	A minimum of 60% brightness contrast between shapes and backgrounds for the low vision individual.
The Netherlands	For normal groups, the difference in reflectance of signage and background of signage and background must be $\geq 0.30$ , and the reflectance values of white and black are 0.85 and 0.04, respectively. However, the rationale for the values is not provided.
Sweden	Due to weathering and discoloration, the brightness contrast diminishes overtime. Therefore, for normal groups, some institutions believe that a brightness contrast of 60% is not recommended and should be set it to 70%.
UK	For low vision individuals, the brightness contrast between the wall and the signboard should be 70%. However, no quantitative experimental data are provided.
USA	The brightness contrast should be more than 70%.
Canada	A recommendation of 70% brightness contrast between the foreground and background (NCS color system) is provided without any further information.
China	The background color of the pedestrian directional signages and the brightness contrast between brightness and dark of the layout elements should not be less than 30%.
ISO 21542 [36]	The proposed brightness contrast for signage is 60%.

The signage size affects people’s recognition of signage, and appropriate signage size can help individuals better understand signage information. Research on signage size mainly focuses on two aspects: the size of the characters and the size of the signage icons. In the literature collected from 10 countries or regions in this study (Table 2), the relationship between character size and distance ranges from 1.8% to 9%, with a mean of 4.28%. The United States is the birthplace of “universal design,” and research and regulations on accessible signage are more advanced. Peters and Smith propose formulas for user-friendly signage font design [37,38]. Loomis provides indicators for the near-sight font size for low vision individuals [39]. Holmes-Siedle suggested several installation heights for accessible signage [40]. British standards stipulate a minimum height of 2300 mm for suspended signage, and font heights should be 5.7% of the viewing distance [41]. Japan’s “Accessibility

Transportation Law” simply specifies the installation height of accessible signage as the arithmetic mean of adult eye height and wheelchair eye height, which is 1.35 m [42].

**Table 2.** The calculation method for the size of signage (and its characters or letters) [21,32,43].

Standards	Recommended Letter Scale	Recommended Character Scale	Size and Reading Distance	Remark
Belgium	—	1.8–3.5%	2–4%	Depending on the importance of information displayed Text information should be supplemented by symbols for understanding
The Netherlands	—	5% of critical reading distance	5%	Contrasting letters must have a minimum ratio of 1:3 to the background
Luxemburg	—	—	3.75%	
Ireland	—	At least 15 × 15 cm	6%	Absolute minimum of 1.5–2.5 cm Emergency signs should be sized larger, as they may need to be followed in smoky conditions and/or without good lighting
United Kingdom	Minimum Size (1.5–2.5 cm) Medium (5–10 cm) Long distance (>15 cm)	The overall height of the symbol should be at least 10 cm, if space permits	Average of 5%	Symbols are generally better than words
Spain	—	—	2.75% (minimum 1.4%)	—
Sweden	The character size cannot be increased indefinitely because the text is no longer readable when low vision individuals get too close to the signage	—	2% (minimum 1.5%)	—

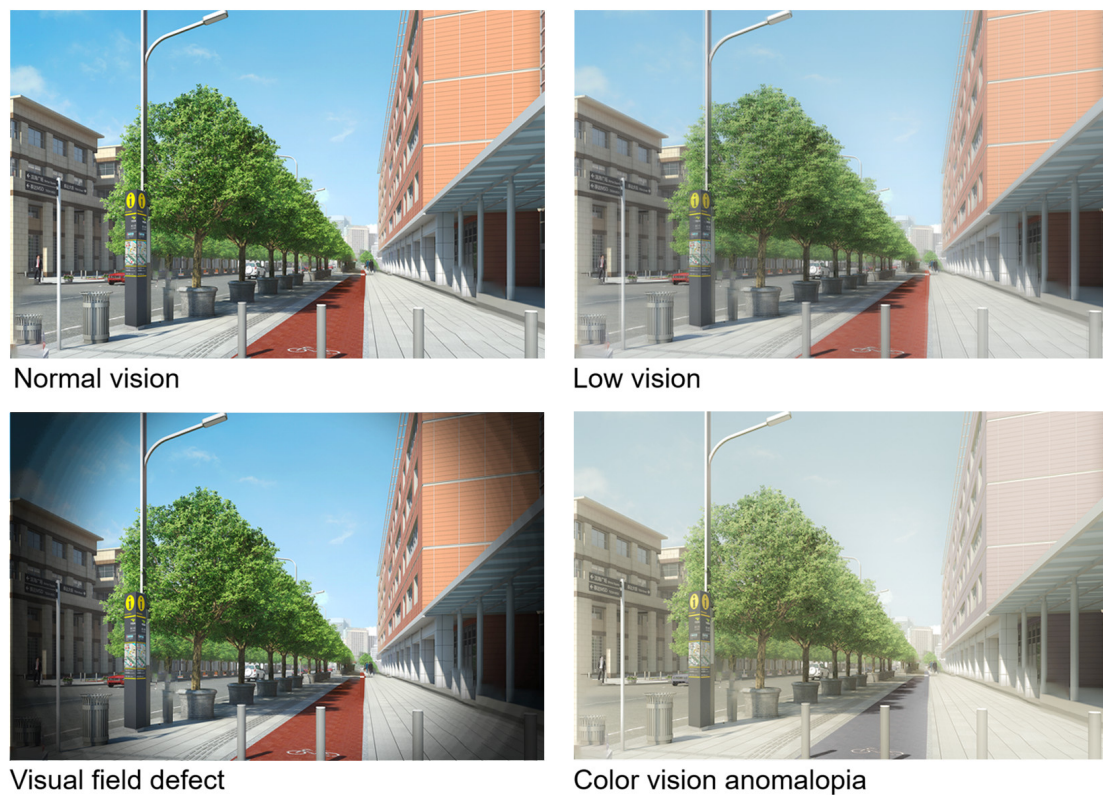
Compared to characters, only a few countries have regulated symbol sizes, and the regulations on the sizes that meet the needs of low-vision people are also relatively messy. Moreover, there are significant structural differences between Latin alphabet characters and Chinese characters. Regarding the requirements for Chinese characters, their use for individuals with visual impairments are likely to be significantly different, and further research is needed. Therefore, this study also seeks to investigate signage size in the context of Chinese characters.

## 2. Experimental Design

### 2.1. Enrollment and Determination of Visual Status

The experimental design focuses on the visual evaluation characteristics of individuals with clinically diagnosed low vision [44]. Upon enrollment, participants were grouped based on a combination of subjective assessments and objective experimental methods [45]. Visual acuity tests were conducted on the subjects at the experimental site, and they were

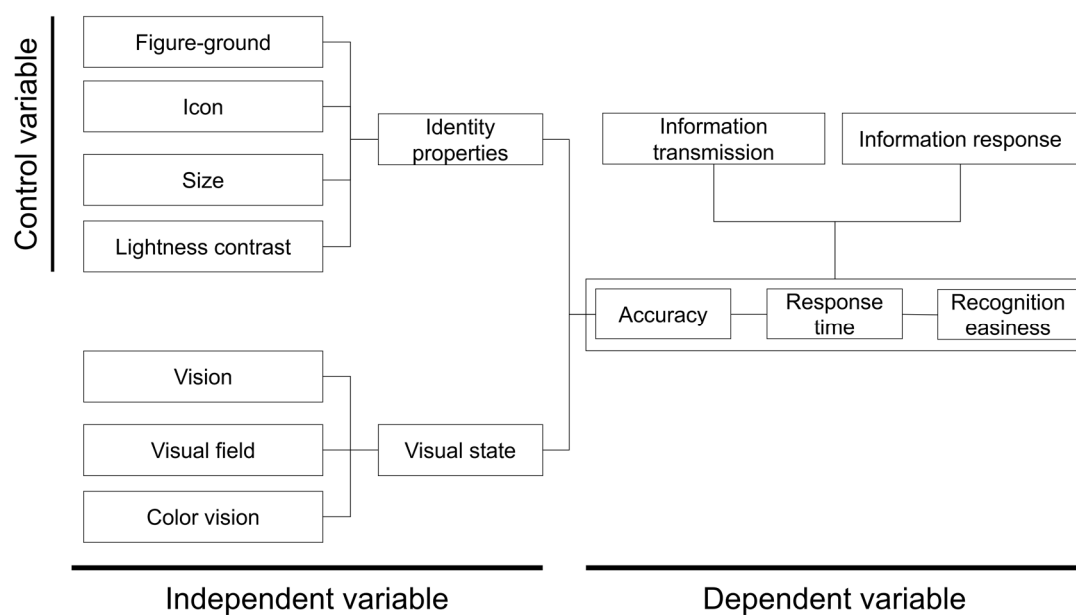
divided into four groups according to their visual acuity status, including normal vision, low vision, visual field defect, and color vision anomalopia, as illustrated in Figure 1 [22].



**Figure 1.** The same scene observed through different vision impairments (created by authors).

## 2.2. Experiment Setup

Figure 2 presents the experiment setup. The experiment variables included shape, size, and brightness contrast, and spatial environmental variables such as uniform lighting are controlled.



**Figure 2.** Configuration of experimental variables.

(1) Signage Selection: Ten common signs were selected from the Chinese National Standard Library [35], including five white-on-black signs and five black-on-white signs shown in the bottom two rows in Figure 3. The texts were in sans-serif font and were divided into five white-on-black and five black-on-white signs. In addition, the top two rows in Figure 3 present the ten image signs included, resulting in a total of twenty signs.



Figure 3. Signage for experiments.

(2) Signage Size: Five different sizes, which were determined by the height of signage and word, were chosen that equaled sizes of 4.5, 13.5, 22.5, 31.5, and 40.5 cm, which corresponded to 1%, 3%, 5%, 7%, and 9% of the reading distance (4.5 m) from the screen respectively. (3) Brightness Contrast: Five levels were chosen as illustrated in Figure 4. The contrast intensity used in Experiments 1 and 2 were predetermined according to Table 1, and the values were 14%, 21%, 33%, 60%, and 76%. The selection of signage size and brightness contrast was based on the guidelines provided in Reference [22].

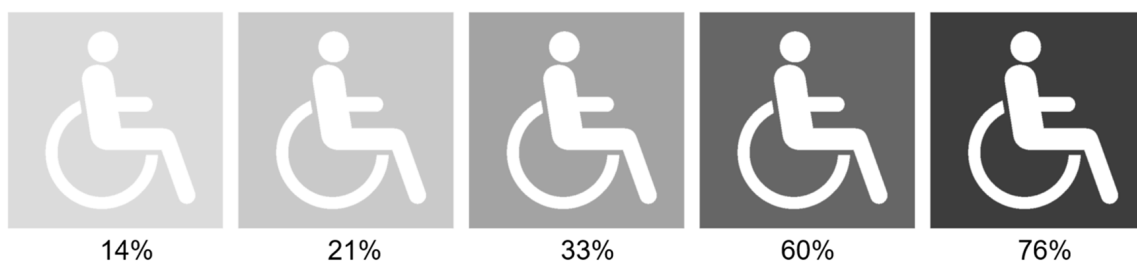


Figure 4. Examples of the different brightness contrast signage.

### 2.3. Procedure

After the participants entered the experiment room, the research objectives and experimental procedures were introduced. Clinical visual function tests (visual acuity measurement, visual field testing, and vision color measurement) and medical history inquiries were conducted first, followed by the execution of the experiments. The entire protocol

is described in Figure 5. The experiment was divided into two sets of tasks. One was called information transmission, and the other was called information response. Two primary aspects of visual accessibility were studied; the first was the ability to locate the position of the signs in space, and the second was the accuracy of identifying or reading the signage’s information [46].

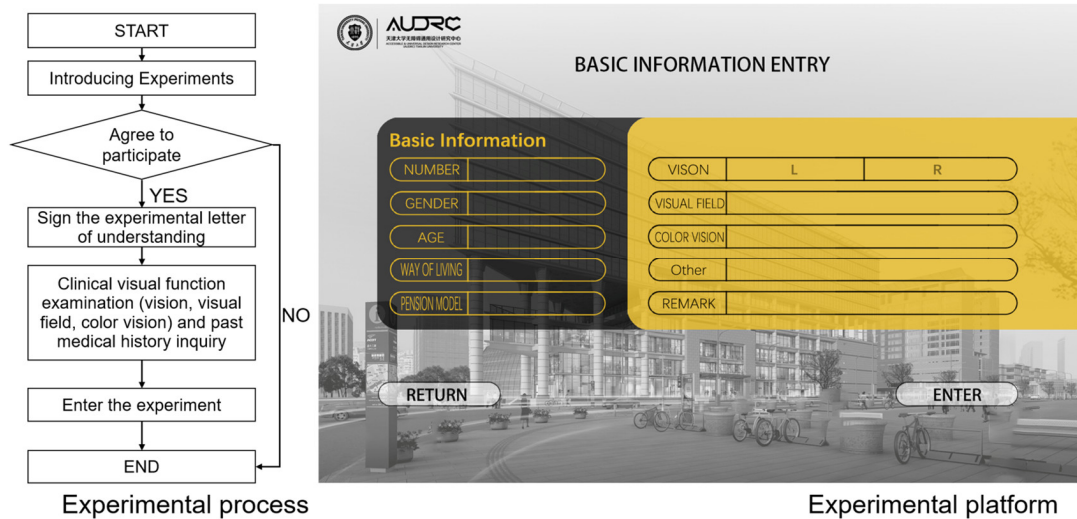


Figure 5. Experimental process.

Experiment 1: Information transmission experiment

In the first experiment (Figure 6), there are 20 signages with 5 sizes and 5 brightness contrasts, resulting in 500 different signages. The participants conducted the experiment at a distance of 4 m from the screen.

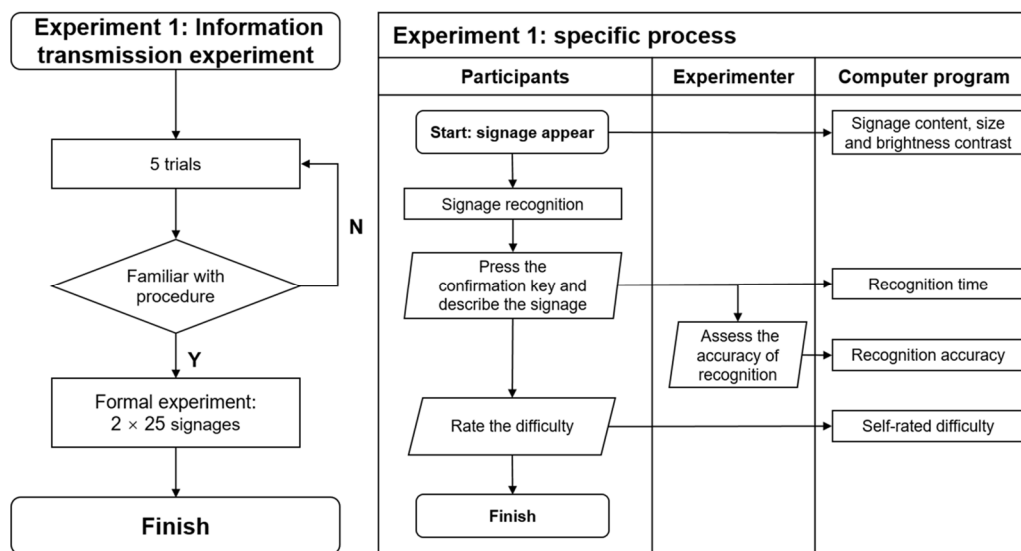


Figure 6. Flowchart of Experiment 1.

Before starting the experiment, participants performed five trials to learn the procedure. When a signage appeared, if the participants recognized it, they pressed the confirmation key and verbally described the meaning of the signage. They were also required to rate the difficulty of their information recognition process on a scale of 1 (very difficult) to 5 (very easy). Additionally, the experimenter assessed the accuracy of the participants’ recognition and recorded the time taken for recognition of each signage.

Each participant completed two sets of experiments, with 25 instances of signage recognition in each set. There was a 3-min break between the two sets to mitigate the potential impact of visual fatigue.

#### Experiment 2: Information response experiment

In real-world scenarios, visual elements, sounds, and other perceptual factors can affect the recognition of signage information. Therefore, Experiment 2 (Figure 7) embedded the signages used in Experiment 1 into images of real-life scenes to simulate the real world.

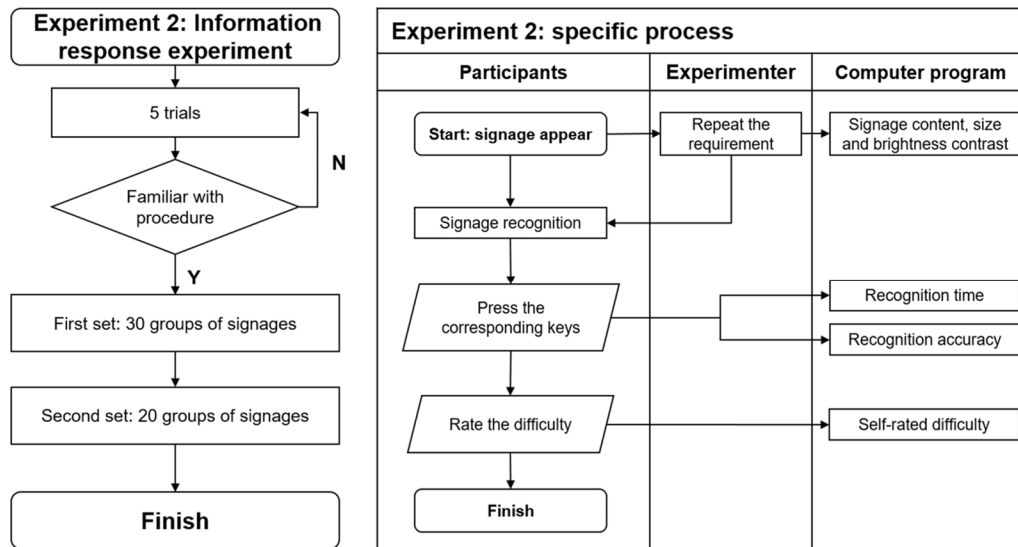


Figure 7. Flowchart of Experiment 2.

Similarly at the beginning of the experiment, participants performed five trials to familiarize themselves with the procedure. Nine random signages with the same size and brightness contrast but different contents were displayed, and participants were asked to identify a particular signage. They had to press a corresponding key on a 9-key keyboard representing the position of that target signage and rate the difficulty level as described for Experiment 1.

Each participant completed two sets of experiments. The first set consisted of 30 groups of random signages (with sizes of 1%, 3%, and 5% and brightness contrasts of 14%, 21%, 33%, 60%, and 76%), and the second set consisted of 20 groups of random signages (with sizes of 7% and 9% and brightness contrasts of 14%, 21%, 33%, 60%, and 76%).

### 3. Experimental Results

#### 3.1. Descriptive Statistics

##### 3.1.1. Experiment 1

A total of 153 participants participated in the experiment, and 139 valid sets of experimental data were collected. The control group consisted of 30 individuals with normal vision, while the low vision group included 75 individuals with low vision, 16 individuals with visual field defects, and 17 individuals with color vision anomolopia. These participants were recruited through posters and social media platforms, and the experiment took place in Tianjin, China. Raw data were preprocessed using the percentile method in Python to remove the outliers. Further analysis, including data correlation and path analysis, was conducted using Statistical Product and Service Solutions (SPSS) software.

##### 1. Accuracy

The size of the signage was positively related to its legibility. Figure 6 shows that as signage size increased from 1% to 3%, the accuracy increased rapidly, while the effect of increasing brightness contrast on accuracy was not profound. The low vision, visual

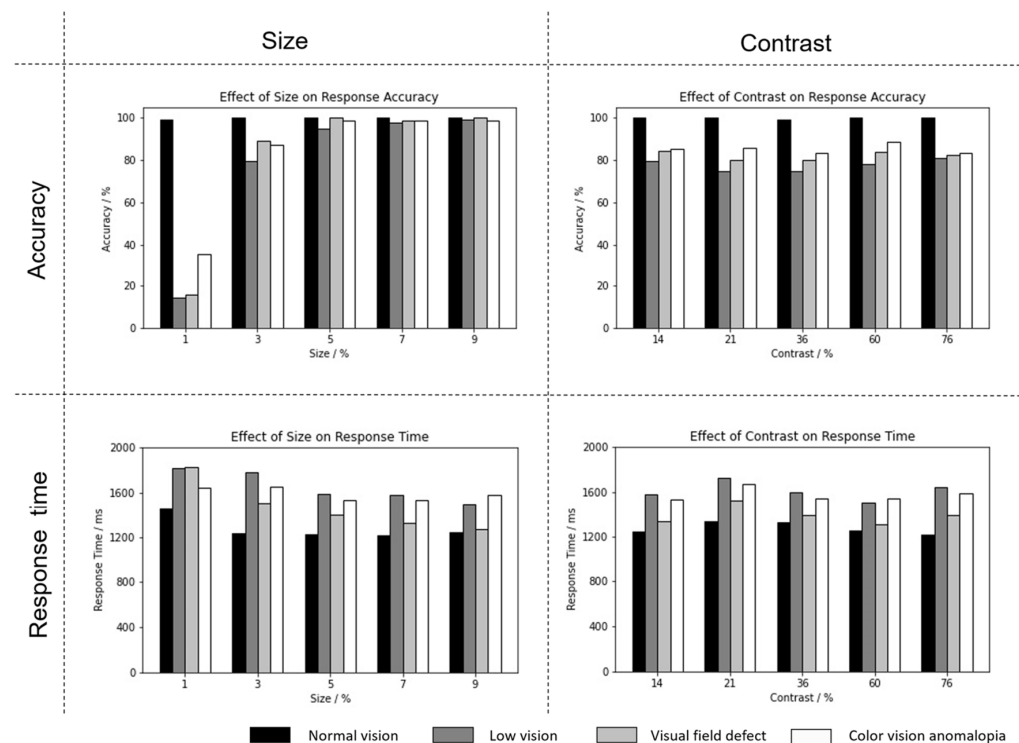
field defects, and color vision anomalia groups all showed significant improvements in response accuracy with larger signage sizes, but the growth rate of response accuracy gradually slowed down at 5%, 7%, and 9%.

Response accuracy for the four groups remained relatively constant at different contrast levels. Under a fixed brightness contrast condition, the response accuracy of the groups ranked from high to low was as follows: normal group, color vision anomalia, visual field defect, and low vision group.

## 2. Response time

Only the response time of correct identification was used in the analysis. The larger the signage size was, the shorter the time needed for signage recognition. For the low vision and visual field defect groups, the response time was influenced by different signage sizes, with time decreasing as size increased. However, color vision anomalia individuals did not exhibit a clear trend in changes. When the signage size reached 5%, the decreasing trend in response time slowed down. Among the four groups, the groups with low vision and visual field defects were more sensitive to changes in signage size.

Brightness contrast had a slight effect on response time for all four groups, but the effect was not significant and showed no trend. Brightness contrast had a more significant impact on low vision and color vision anomalia groups. For the low vision group, brightness contrast values of 21% and 76% had a significant effect on response time, while other values were not significant (Figure 8).



**Figure 8.** The accuracy and response time results for Experiment 1.

## 3. Difficulty level

All groups exhibited a decrease in response difficulty as signage size increased. On the one hand, effective growth was observed from 1% to 5% signage size, and the growth trend slowed down after 5%. On the other hand, brightness contrast had a relatively small impact on response difficulty. There were differences in average response difficulty under different brightness contrasts, but the impact was not profound and did not show a trend. Under a fixed signage contrast, the order of response difficulty was normal vision group > color vision anomalia > visual field defect > low vision group (Figure 9).

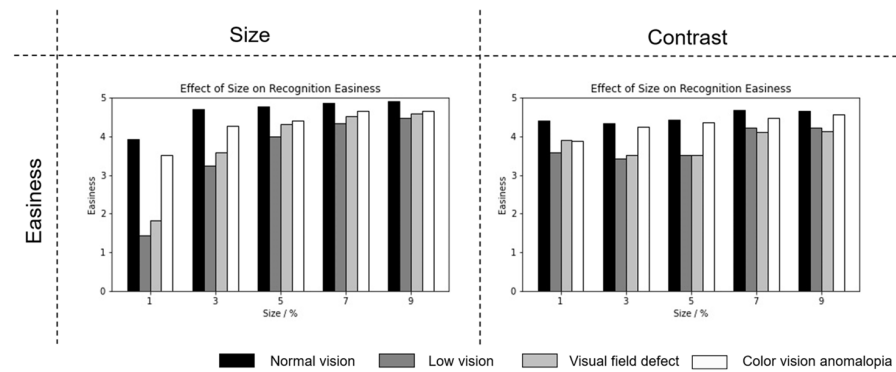


Figure 9. The difficulty level results for Experiment 1.

### 3.1.2. Experiment 2

#### (1) Accuracy

All groups exhibited a significant improvement in response accuracy with increasing signage size (Figure 10). The low vision and visual field defect groups had much higher accuracy than the normal group at 7% and 9% signage sizes. Based on the follow-up interview, this might be due to the fact that the low vision group had a strong desire to get correct results, thereby spending more time. In the response experiment, at smaller sizes, the response accuracies of the low vision, visual field defect, and color vision anomolopia groups were much higher than those obtained in Experiment 1 and only slightly lower than that of the normal group. There was no significant difference in response accuracy among the four groups at different contrast levels in the response experiment. The response accuracy of the normal vision, visual field defect, and color vision anomolopia groups ranged from 80% to 86%, while the response accuracy of the low vision group was slightly lower, ranging from 76% to 79%, representing the lowest values.

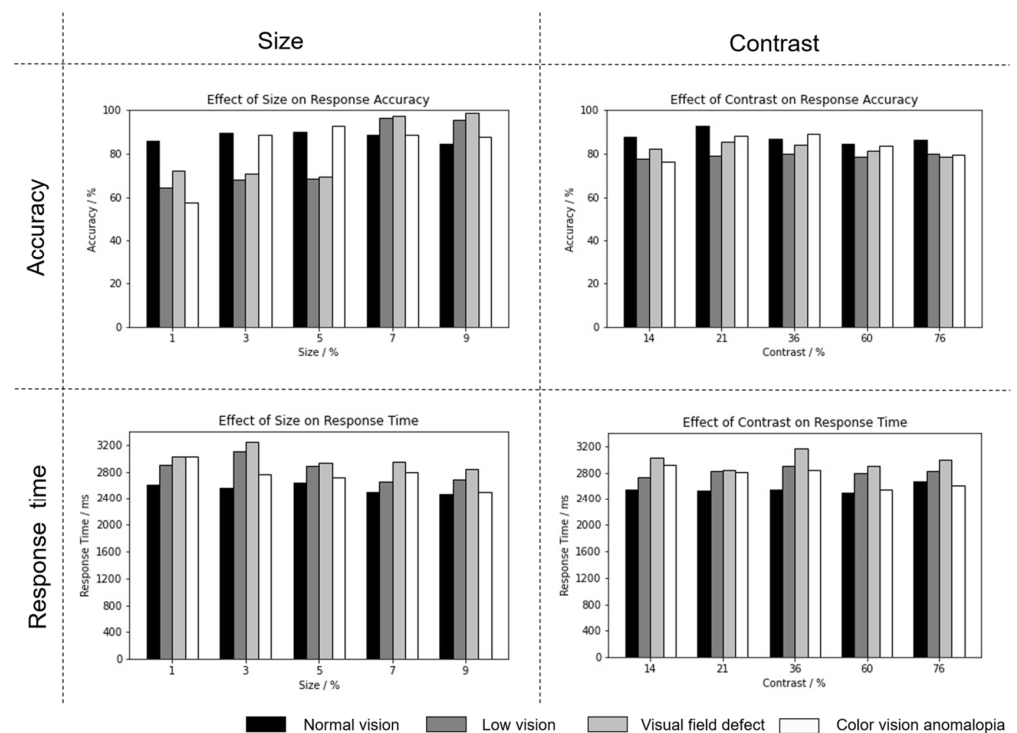


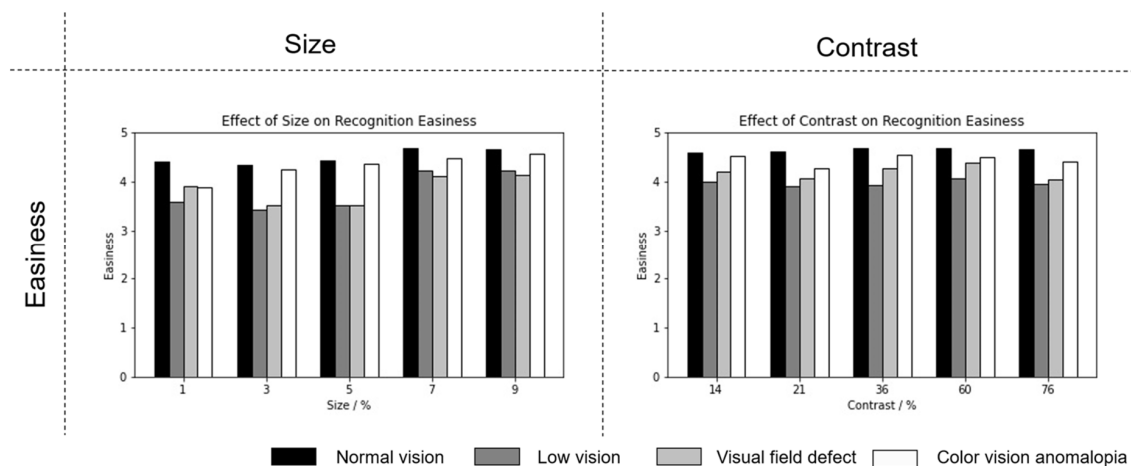
Figure 10. The accuracy and response time results for Experiment 2.

#### (2) Response time

As in Experiment 1, only the response times of correct identification were used in the analysis. Overall, as the size of the signage increased from 3% to 9%, the time spent searching and identifying the signage decreased. Among the low vision, visual field defect, and color vision anomopia groups, the response time decreased as the signage size increased. However, for signage sizes of 1% and 3%, the response time of the low vision and visual field defect groups increased with the increase in signage size. The brightness contrast had little effect on identification time. The response time for the four groups were relatively stable and did not differ significantly at different brightness contrasts. Under a fixed signage size and brightness contrast, the order of response time for the four groups from the lowest to highest was as follows: the normal group, color vision anomopia group, visual field defect group, and low vision group (Figure 10).

### (3) Difficulty level

As signage size increased, the response difficulty decreased. The impact of brightness on difficulty was smaller than that of size. Under different brightness contrasts, individuals with anomopia felt that the tasks were easier to perform than those with low vision and visual field defects. However, the difference between the groups with low vision and visual field defects was not significant (Figure 11).



**Figure 11.** The difficulty level results for Experiment 2.

### 3.1.3. Correlation between Experiments 1 and 2

As the low vision group accounted for most of the participants and their response results were mostly at a lower level, this experiment further analyzed the interactive relationship between signage size and brightness contrast, specifically for the low vision group.

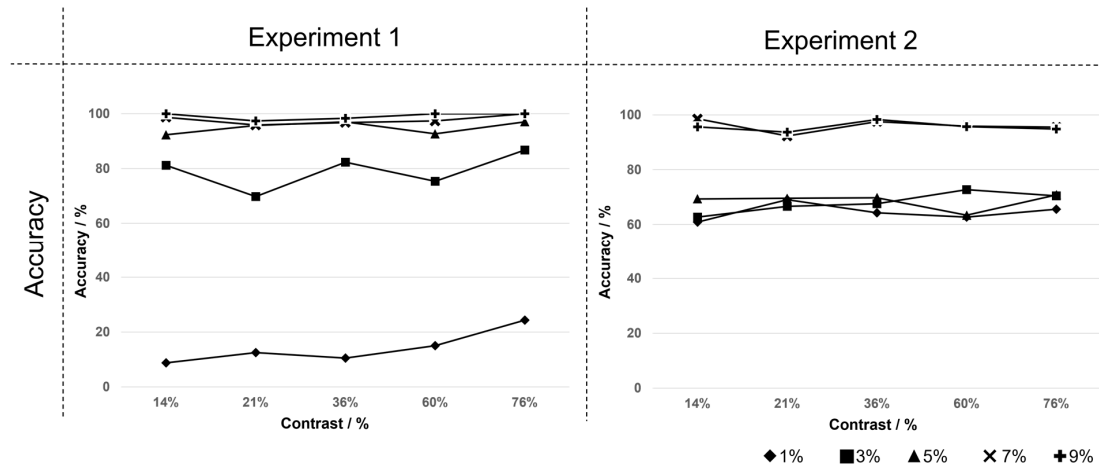
#### (1) Accuracy

In Experiment 1, signage size significantly impacted response accuracy, with larger signage sizes leading to higher response accuracy. When the signage size was below 5%, the brightness contrast was an important factor in improving recognition accuracy. At 1% and 3% contrast levels, brightness contrast still had a significant effect on improving the rate of correct identification. At the 1% contrast level, as compared to the three curves with the largest sizes (5%, 7%, and 9%), the response accuracy significantly increased as brightness contrast increased. In the three cases where the sizes were 5%, 7%, and 9%, the influence of brightness contrast on response accuracy was relatively weak.

In Experiment 2, for low vision individuals, similarly, larger signage sizes led to higher response accuracy. When the signage size reached 7%, the response accuracy increased to over 90%. In the cases when size was 1%, 3%, and 5%, the response accuracy was clustered between 60% and 75%.

Compared to Experiment 1, Experiment 2 required a higher signage size to improve response accuracy, as shown in Figure 12. The response accuracy for the 7% and 9% sizes

reached over 90%. In the 5% case, the accuracy of Experiment 2 was significantly lower than that of Experiment 1, with a difference of 26.37%. In the 3% case, the accuracy of Experiment 2 also slightly decreased, with around 60% and 70% response accuracy. In the 1% case, however, the accuracy of Experiment 2 reached 50.29%.

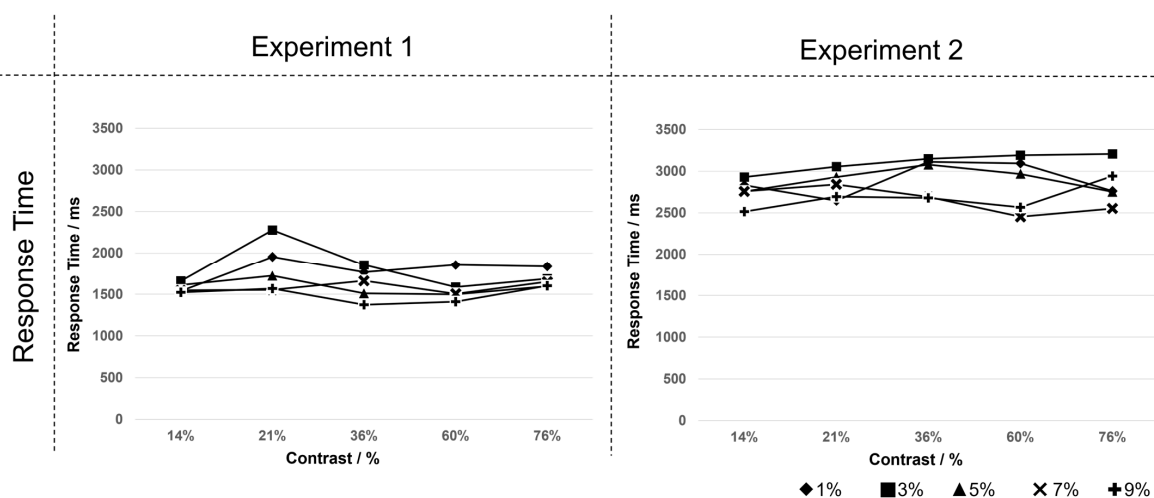


**Figure 12.** The comparison of accuracy results between Experiments 1 and 2.

## (2) Response time

Data from Experiment 1 showed that the response time of the low vision group was clustered in a range between 1500 ms to 2300 ms, and as signage size increased, the response time decreased. For different signage sizes, the difference in response time was significant when the contrast increased from 14% to 21%. However, when the contrast increased to 36%, the response time decreased rapidly and reached a plateau. When the contrast increased to 60% and 76%, only little variation in response time was observed in terms of size variations.

Compared to Experiment 1, Experiment 2 showed a longer response time that ranged from around 2500 ms to 3200 ms, and as signage size increased, the response time decreased. For the same combination of brightness contrast and size, all response time data in Experiment 2 were greater than those in Experiment 1. It could be inferred that low vision individuals spent more time searching for signage during the recognition process than they did when the signage was already located (Figure 13).



**Figure 13.** The comparison of response time results between Experiments 1 and 2.

### 3.2. Path Analysis

A statistical model was established to explore the different factors that affect accuracy and response time using the method of path analysis.

#### 3.2.1. Experiment 1

The independent variables of Experiment 1 consisted of signage attributes and visual state. Signage attributes included both signage size and brightness contrast, while visual state included vision, visual field, and color vision (Table 3). The following conclusions could be drawn:

- (1) When the dependent variable is accuracy, visual acuity ( $r = 0.272$ ,  $z = 18.210$ ,  $p = 0.000 < 0.01$ ) and signage size ( $r = 0.517$ ,  $z = 35.424$ ,  $p = 0.000 < 0.01$ ) are significantly positively correlated with accuracy.
- (2) After excluding experimental data with erroneous response results in Experiment 1, analysis with correct response time as the dependent variable found that vision ( $z = -12.438$ ,  $p = 0.000 < 0.01$ ) and signage size ( $z = -6.885$ ,  $p = 0.000 < 0.01$ ) are significantly negatively correlated with response time. Color vision ( $z = -2.432$ ,  $p = 0.015 < 0.05$ ) is negatively correlated with response time. Moreover, the visual field ( $z = 5.575$ ,  $p = 0.000 < 0.01$ ) is significantly positively correlated with response time.
- (3) When the dependent variable is self-rated difficulty, vision ( $z = 26.468$ ,  $p = 0.000 < 0.01$ ) and signage size ( $z = -3.369$ ,  $p = 0.001 < 0.01$ ) are significantly positively correlated with self-rated difficulty. Color vision ( $z = 44.096$ ,  $p = 0.000 < 0.01$ ) is negatively correlated with difficulty.

**Table 3.** Model regression coefficients (Experiment 1).

X	→	Y	z (CR Value)	p
Vision	→	Accuracy	18.210	0.000 **
Visual field	→	Accuracy	-1.567	0.117
Color vision	→	Accuracy	0.651	0.515
Signage size	→	Accuracy	35.424	0.000 **
Brightness contrast	→	Accuracy	1.143	0.253
Vision	→	Response time	-12.438	0.000 **
Visual field	→	Response time	5.575	0.000 **
Color vision	→	Response time	-2.432	0.015 *
Signage size	→	Response time	-6.885	0.000 **
Brightness contrast	→	Response time	-0.932	0.351
Vision	→	Difficulty	26.468	0.000 **
Visual field	→	Difficulty	-1.397	0.162
Color vision	→	Difficulty	-3.369	0.001 **
Signage size	→	Difficulty	44.096	0.000 **
Brightness contrast	→	Difficulty	1.271	0.204

Remarks: → means path influence relationship, \* means  $p$  value  $< 0.05$ , \*\* means  $p$  value  $< 0.01$ , CR means critical ratio.

#### 3.2.2. Experiment 2

The data model of Experiment 2 (Table 4) is identical to that of Experiment 1, yielding the following conclusions:

- (1) When the dependent variable is accuracy, vision ( $z = 6.787$ ,  $p = 0.000 < 0.01$ ) and signage size ( $z = 12.904$ ,  $p = 0.000 < 0.01$ ) are significantly positively correlated with accuracy.
- (2) After excluding experimental data from Experiment 1 with incorrect response results, analysis of correct response time as the dependent variable revealed that vision ( $z = -5.513$ ,  $p = 0.000 < 0.01$ ), visual field ( $z = -4.038$ ,  $p = 0.000 < 0.01$ ), and signage size ( $z = 12.904$ ,  $p = 0.000 < 0.01$ ) are significantly positively correlated with response time.
- (3) When the dependent variable is self-rated difficulty, vision ( $z = 18.150$ ,  $p = 0.000 < 0.01$ ) and signage size ( $z = 19.523$ ,  $p = 0.000 < 0.01$ ) are significantly positively correlated

with self-rated difficulty. Color vision ( $z = -3.092, p = 0.002 < 0.01$ ) is significantly negatively correlated with self-rated difficulty.

**Table 4.** Model regression coefficients (Experiment 2).

X	→	Y	z (CR Value)	p
Vision	→	Accuracy	6.787	0.000 **
Visual field	→	Accuracy	-0.752	0.452
Color vision	→	Accuracy	0.419	0.675
Signage size	→	Accuracy	12.904	0.000 **
Brightness contrast	→	Accuracy	0.006	0.995
Vision	→	Response time	-5.513	0.000 **
Visual field	→	Response time	-4.038	0.000 **
Color vision	→	Response time	0.149	0.881
Signage size	→	Response time	-5.646	0.000 **
Brightness contrast	→	Response time	-0.119	0.906
Vision	→	Difficulty	18.150	0.000 **
Visual field	→	Difficulty	0.599	0.549
Color vision	→	Difficulty	-3.092	0.002 **
Signage size	→	Difficulty	19.523	0.000 **
Brightness contrast	→	Difficulty	1.342	0.180

Remarks: → means path influence relationship, \*\* means  $p$  value  $< 0.01$ .

#### 4. Discussion

The experiment has demonstrated that an increase in signage size improves information recognition accuracy and reduces the time required for information recognition. The response accuracy reached a stable high-accuracy state when the signage size was 7% of the reading distance. Therefore, to ensure greater universality, it is recommended that 7% of the reading distance be the minimum size for the signage design. However, the results of the response time analysis differed slightly from those of the response accuracy. In the case of signage recognition, low-vision individuals can quickly identify the correct signage when the signage size is 7% or greater than the reading distance. At 9%, the signage recognition level was mostly acceptable. Increasing the symbol size made identification more comfortable for low-vision individuals. Therefore, the experimental recommendation for signage size should not be lower than 7% of the reading distance. If it is lower than 7%, low vision individuals would face more problems in wayfinding. The relationship between the observation distance and the signage size is summarized in the following formula:

$$L = 0.07D \quad (4)$$

where  $L$  is the short side length of the signage (m), and  $D$  is the maximum observation distance (m).

This minimum size recommendation is larger than the recommendation for accessible signage in the Japanese "Barrier-Free Building Design Guide" [39] possibly because Chinese characters are more complex in structure than Japanese characters as an increase in the number of strokes may decrease the legibility of signage fonts. The increase in the number of strokes makes the Chinese characters more crowded, reduces the space between strokes, obscures the details and features of the characters, lowers their recognizability, and ultimately leads to an increase in cognitive processing time. The 7% size limit meets the standards proposed by Den Brinker et al. [47] and the United Kingdom Sign Design Guide and is greater than the average guidelines of European Union countries. The recommended signage value from this experiment is also greater than the ADA Standard for Accessible Design Act, Section 703.5.5 [43]. However, it is smaller than the recommended minimum scale of graphic symbols for signage boards in Article 41 of China's "Building

Construction-Accessibility and Usability of the Built Environment” (ISO 21542) [42], which suggests the following:

$$L = 0.09D \quad (5)$$

where  $L$  is the short side length of the signage (m), and  $D$  is the maximum observation distance (m).

Compared with Experiment 1, the recognition effect of Experiment 2 differed significantly. Based on interviews conducted after the experiment, it was evident that accurate communication of information and the search for responsive icons did not present equivalent levels of visual recognition difficulty. Moreover, factors such as the familiarity of symbols among the subjects could affect the accuracy of their response. Notably, a considerable number of participants found it challenging to identify signs that they were unfamiliar with or those that had high similarities in their morphology. This underscores the critical need for a unified and clear design of signage graphics.

The impact of brightness contrast on response accuracy was strongly dependent on changes in signage size. When the size of the signage was less than 5%, the brightness contrast of the signage was a dominant factor affecting the correct recognition rate. In cases where the signage size was 1%, increasing the brightness contrast significantly improved the accuracy of the response. However, this did not reveal a clear quantitative relationship, which indicated that a signage size of approximately 1% reading distance was not sufficient to meet the wayfinding needs of individuals with low vision. Even though increasing brightness contrast could improve recognition efficiency, it still failed to satisfy the desired results for universal design. Furthermore, the experimental results showed that when the signage size reached 5% reading distance, the impact of brightness contrast on recognition accuracy rapidly decreased. However, it still helped to improve the recognition efficiency. These conditions are based on fixed-point signage recognition discussions. In actual spatial relationships, the specific relationship between individuals and signage is a variable that is not fixed. Therefore, it is recommended that the brightness contrast should be as high as possible to meet the wayfinding needs of different groups of people in different scenarios.

The conclusions drawn above apply to the general population with low vision ( $0.3 > v \geq 0.05$ ). Among the diverse individuals with visual impairments, some need more time to identify signages than others. For example, in groups with visual field impairment, there was a linear decrease in response time with an increase in signage size. In Experiment 2, if the signage size exceeded the subjects’ visual range, individuals with low vision must adjust their gaze through eye or head movements, resulting in a longer response time for signage recognition. Therefore, multiple factors must be considered in determining signage size. Additionally, it was found in the experiment that many commonly used symbols were composed of multiple parts, and the results of the experiment as well as post-interview feedback indicated that these details were difficult for individuals with low vision to recognize. Thus, a unified, concise, and accurate signage image is helpful for low vision individuals. In addition, the participants mostly believed that a combination of figures and text ensured the successful transmission of information.

This study provides reference data for the design of signage recognition size and brightness contrast for individuals with low vision. This research specifically focused on three subgroups: individuals with low vision, individuals with visual field defects, and individuals with color vision anomalia. However, the variety of underlying causes and visual function types in these groups indicates a wide range of visual impairment characteristics. Consequently, the findings are still inefficient to be considered as guidelines applicable to low vision people at the individual level. The element interaction discussed in this study suggests that signage guidelines based on single-element experiments are not complete. Moreover, the placement of signage in a space is also very important. The consensus is that signage should be uniformly positioned in clearly visible locations throughout the entire architectural space, and it must not interfere with the activities of the users. Brightness contrast and size are only two factors that may affect visual information acquisition; therefore, before developing standard design guidelines, more experiments should

be conducted in the future to further refine specialized research on lighting, positioning, signage design, and other relevant elements as well as their interactions. Moreover, due to inherent limitations in laboratory research, subsequent studies in real-world scenarios are essential to validate and assess the practicality of these experimental conclusions. The application of these findings will require verification in varied real-world settings, encompassing different lighting conditions, diverse environmental contexts, and a broader spectrum of user participation. This approach will facilitate the development of inclusive design guidelines that address both universal and specific needs.

## 5. Conclusions

Ensuring the legibility of signage recognition for individuals with low vision is crucial. However, developing reasonable, clear, actionable, appropriately scoped, and fair accessibility guidelines for all stakeholders poses significant challenges. This paper shows that signage size and brightness contrast have significant influence on signage legibility. The afore-provided signage design recommendations not only improve the effectiveness of conveying information but also enhance spatial accessibility for low vision individuals. Furthermore, these recommendations offer more viable design choices for graphic designers and signage manufacturers, benefiting the practices of universal design and architectural signage groups.

In addition, an intelligent experimental platform was developed to quantify the impact of brightness contrast and size on signage design in this study. By analyzing response accuracy and response time, it provides a mathematical and precise approach to signage design. The platform's applicability extends to universal signage design and other related studies, facilitating the quantitative evaluation of multiple signage design elements such as font, line spacing, color, size, icon, and brightness contrast. Its versatility and expandability make it a valuable tool in the field of signage design and beyond.

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