Perception Measurement of Interface Transparency on the Side of Living Commercial Streets in North China

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Abstract. Street space is a place where residents engage in daily activities, and its environmental design plays an important role in regulating the physical and mental comfort of people. However, the visual environment of street space is complex with many design elements, which is not conducive to grasping the design focus. Based on visual perception of comfort, the study deconstructs street space design into four basic elements: interface transparency, storefront density, interface colors and interface materials, and builds a virtual scene using SU software. The combination of human factors experiments and questionnaires is used to study the perception of street transparency, providing basic information and new research methods for the humanized design of the visual environment of street space.

Keywords. Human factors experiment, living street, side interface, virtual scene.

1. Introduction

As an important public space in a residential area, living commercial streets will affect the activity habits and lifestyles of the residents, and a good street space environment can make users maintain a pleasant and comfortable perceptual experience and comfortable psychological feelings can also be reversed to know the street space design. Professor Xu Leiqing of Tongji University and others used virtual reality technology to summarize the influence of architectural interface and green view rate on street charm [1]; Zhang Yifan and Zhou Yu used experimental psychology to establish a “physical form-space cognition” model to investigate the parameters of architectural interface density and line rate. quantitative methods [2]; Yu Ye and Xiaoling Dai introduced the application of machine learning, virtual reality, eye-tracking and physiological sensing in the study of “spatial-perception-behavior” urban environments through a number of practical cases [3]. Long Ying’s team at Tsinghua University proposed the concept of human-scale urban form based on pioneering urban research methods and techniques such as eye-movement technology and data mining and visualization, focusing on the spatial patterns and their associated effects that people frequently encounter in their daily lives [4]. Through physiological signal analysis, the connection between human perception and street environment creation is investigated, and relevant methods of material space creation are proposed to provide new research methods and more microscopic data from a human perspective. This paper attempts to analyze the interface design elements of living commercial streets by combining human factors experiments and subjective questionnaires and conducts a quantitative study on visual comfort so as to refine and humanize the interface design elements of street space more specifically.
2. Deconstruction of Visual Design Elements of Street Space

Vision is the most important human sense, and more than 80% of the external information that people feel comes from vision [5], therefore, visual information has a crucial influence on human cognition and psychology. When people perceive external shape, color, spatial position and other physical information through vision, different visual effects also bring different visual cognition and have an impact on visual comfort. According to the questionnaire survey, the elements that affect visual comfort are ranked according to their degree of influence, and they are interface transparency, storefront density, interface color, and interface material (table 1). Due to the limited space of the article, only the perception measurement study of interface transparency is described in detail.

| Table 1. Interface type division. |
|----------------------------------|
| Interface Transparency | Store Density | Color | Material | Fidelity | Continuity | Decoration |
|--------------------------|---------------|-------|----------|----------|------------|------------|
| **Average female score**  | 3.82          | 3.47  | 3.91     | 3.55     | 3.43       | 3.69       | 4.04       |
| **Average male score**    | 3.48          | 3.48  | 3.84     | 3.8      | 3.53       | 3.35       | 4.17       |
| **Variance**              | 0.84          | 0.89  | 0.82     | 0.85     | 0.84       | 1.12       | 0.71       |
| **Overall Average Score** | 3.7           | 3.65  | 3.89     | 3.63     | 3.46       | 3.57       | 4.09       |

3. Interface Transparency Perception Measurement Experiments

3.1. Experimental Methods

The perception of interface transparency is measured using a combination of human factors experiments and simulations, in which physiological sensors are used to record physiological data under different values of interface stimuli while showing different transparency models to the subjects. Combined with the subjective evaluation of different stimulus signals, the perceptual characteristics of the subjects under different conditions are determined, which is more scientific and accurate.

3.2. Experimental Instruments

During the experiment, the instrument is mainly divided into two parts: human factors physiological signal acquisition and interface simulation, including two laptop computers, EDA and PPG physiological sensors, signal receivers, electrode sheets and sterile cotton. The human factors experiment relies on the ErgoLAB experimental platform, using wearable physiological sensors skin electrical acquisition module and photoelectric volume pulse acquisition module real-time recording of the subject’s skin conductance signal data (EDA) and photoelectric volume pulse signal data (PPG), and through the signal receiver to the computer ErgoLAB software for recording and post-processing. The interface simulation requires the computer to play back a dynamic video of a pre-processed panoramic image of the interface for the subject to view in sequence.

3.3. Interface Transparency Value Selection

Interface transparency represents the proportion of the total street length for interfaces with line-of-sight penetration. This experiment follows the method proposed by Chen and Zhao to calculate street transparency and storefront density: transparency= (Type1 interface length× 1.25+ Type2 interface length+ Type3 interface length× 0.75 + Type4 interface length×0)/ total length of the building interface along the street [6]. In this study, transparent glass doors open directly to the public on the street are classified as Type1 interfaces; glass windows with direct view to the interior are classified as Type2 interfaces; advertising glass windows and transparent glass windows that block the view to the interior are classified as Type3 interfaces; opaque solid walls and opaque advertisements are classified as Type4 interfaces. The transparency of the interface of a sexual commercial street is calculated (table...
Table 2. Classification of interface types.

| Interface transparency type | Class 1 | Class 2 | Class 3 | Class 4 |
|-----------------------------|---------|---------|---------|---------|
| Interface                   | Transparent glass doors that open directly to the public (excluding non-transparent, screened doors) | Direct line of sight to the interior of the glass case | Advertising windows and clear glass windows that are heavily obscured from view | Opaque Solid Wall and Opaque Advertising |

Interface transparency calculation equation:

\[ N = \frac{L_1 \times 1.25 + L_2 \times 1 + L_3 \times 0.75 + L_4 \times 0}{L} \times 100\% \]  

(1)

The interface transparency is closely related to the store windows and window size. According to the results of the preliminary field research on several streets, the interface transparency of the existing lifestyle commercial streets is distributed in the range of 20% to 70%, with four types of interfaces represented, mostly the first and second types. According to the design experience and research results, the lowest value of the interface transparency in this experiment was set at 20%, and the transparency of the other groups was set in increasing order. In the process of setting the values of the experimental variables, it is necessary to consider the visual perceptibility of the interface transparency when it changes, and to ensure the uniformity of the increasing variables.

3.4. Scenario Simulation and Variable Control

In order to strictly control the uniqueness of the variables in the experiment, i.e., only the interface transparency differs among the experimental groups, and this experiment adopts the method of constructing a street interface model to simulate streets with different interface transparency [7]. In addition to avoiding noise, vehicles, and other influencing factors, the modeling process also needs to control the architectural form of the street interface, the density of storefronts, billboards, and other factors that may have a direct visual impact on the subjects, and to minimize extraneous factors such as decorative details that may distract the subjects' attention [8]. In the process of scene creation, the scale of the streets under each experimental scenario was kept constant, and the more common living streets with two-way traffic lanes in the middle and pedestrian space on both sides were used as the basic scene. During the research, it was found that most of the stores in the living streets are one storey, so the number of storeys in this experiment was set to one, and the surrounding buildings were set to be high-rise residential buildings. The architectural style of the ground floor stores is simple and modern, and the interface is made of granite, with the main color being gray. At the same time, the signage layout of each store was consistent and not overly decorated, and the store names were simplified to avoid distracting the subjects. The interface continuity and the building alignment rate were in accordance with the specifications [9]. The total length of the interface in this experiment was kept at about 160 meters, with a residential entrance and exit at 80 meters as a break, and the rest of the interface was kept continuous to ensure that all the stores were in the same plane [10]. The number of stores in the street is consistent across the four scenarios, and the storefront density is controlled to 15.

The four street scenes basically maintain the same interface form, and the different transparency is achieved by adjusting the interface type: the interface model with 20% transparency is based on a transparent glass door that is directly open to the public, and there is no window in the store, which is unified with the other three materials by posting advertisements on the solid wall; the interface with 40% transparency consists of a transparent glass door that is directly open to the public and no direct
line of sight. The interface with 60% transparency is composed of a transparent glass door directly open to the outside and a window with a direct line of sight to the interior; the interface with 80% transparency is composed entirely of a glass door directly open to the outside, with one independent entrance and exit for the smaller and two entrances and exits for the larger stores (table3).

Using Sketchup modeling software, four kinds of street interface models with transparency of 20%, 40%, 60% and 80% were created, and the exported images were collaged with the panoramic map by Photoshop software. The interface transparency model is transformed into a dynamic video with a duration of about 2 minutes, which is randomly played back to the subjects during the experiment to measure the visual perception of interface transparency.

| Table 3. Quantitative Experimental Scenarios and Variable Element Selection. |
|------------------------|------------------------|------------------------|
| Scenario Quantification | Scenario Variables     |
| Street Width            | 18 Meters              |
| Building Forms          | Simple Modern          |
| Materials and Colors    | Gray Granite           |
| Signage & Decoration    | Simplification         |
| Number of Floors        | 1 layer                |
| Store Density           | 15                     |
| Playback Speed          | Approximately 1.2m/s   |
| Sidewalk Pavement Forms | Staggered red rectangular floor tiles |
| Interface Continuity    | One place must be disconnected, the rest remain continuous |
| Architectural Alignment Ratio | All interfaces remain in the same plane |

3.5. Experimental Procedures
In order to ensure that the physiological information data collected during the experiment is only caused by changes in the experimental material, the following measures are taken to avoid interference in the experimental process: (1) A computer screen is placed on a white wall as the background, and other objects within the subject’s line of sight are cleared to ensure concentration during the experiment; (2) Before the experiment begins, the temperature in the subject’s room is appropriate, the subject is comfortably dressed, and the subject’s position is unchanged. These conditions will not be adjusted during the process; (3) The experimental environment will be kept quiet to exclude the psychological or physiological effects of sound or other unstable factors on the subjects.

The experiment was divided into two parts: first, the subjects were instructed to watch four video clips and record their skin conductance data (EDA) and photo volumetric pulse data (PPG); second, the data recording was completed, and the subjects were instructed to fill in the subjective questionnaire.

The experimental procedure was as follows:
1. Explain the principles of the experiment to the subject, introduce the procedure and the purpose of the experiment, and put him/her into a relaxed state.
2. Guiding the subject into position, sitting comfortably in front of the computer, ready to watch the four experimental videos.
3. Clean the subject’s palm and earlobe with alcohol cotton, put the electrode patch on the subject’s palm to ensure that the electrode patch is close to the skin, connect the dermal sensor to the electrode patch to collect the subject’s EDA signal, and put the photo volumetric pulse sensor on the subject’s earlobe to collect the subject’s PPG signal for the next heart rate variability analysis.
4. Have the subject sit relaxed in a quiet environment for 5 minutes and record experimental baseline data.
5. After the baseline acquisition, let the emissaries watch four video clips with different interface transparency, each video is about two minutes, record the start and end time of each video in sequence, and mark and record the start and end of each video in ErgoLAB experimental software to accurately
record the physiological signal data corresponding to each video for later data analysis. Ensure the physiological test module records are complete and continuous during the experiment.

(6) After all four experimental videos have been played, the participants are instructed to rank and evaluate the perceived comfort level of the street interface with different transparency.

(7) Complete the data recording and saving, number the experimental data and the subjective questionnaire to correspond and end the experiment.

4. Data Analysis

A total of 33 subjects were invited for this experiment, with 30 valid subjects, including 13 males and 17 females. The electrodermal data and photoelectric volumetric pulse signals under different interface transparency stimuli were visualized and transferred by ErogoLAB software for further statistical analysis.

4.1. EDA Data Analysis

In figure 1, when the subject is exposed to external stimuli, the curve will fluctuate significantly, producing peaks. After data collation, the raw averages of the electrical skin signals of 30 subjects at four interfacial transparency levels were obtained (table 4). In order to avoid bias due to individual differences, the data were normalized. Each subject’s SC signal values at different interface transparency levels were mapped to decimals in the range of 0 to 1, and each data was transformed into a proportion of the total personal data value, which was the sum of the baseline and the SC signal values at the four different interface transparency levels, with each subject’s transformed data summing to 1 (figure 2).

|                  | Baseline | Interface Transparency |
|------------------|----------|------------------------|
|                  |          | 80%        | 60%        | 40%        | 20%        |
| Female Avg.      | 0.277    | 0.222      | 0.173      | 0.161      | 0.167      |
| Male Avg.        | 0.229    | 0.223      | 0.186      | 0.177      | 0.186      |
| Combined average | 0.256    | 0.222      | 0.179      | 0.168      | 0.175      |
| Variance         | 0.005    | 0.001      | 0.001      | 0.002      | 0.002      |
| Rate of change   | ---      | 13.2%      | 30.3%      | 34.5%      | 31.6%      |

Figure 1. EDA signal curve and Skin electrical signal analysis results in.

Table 4. Mean value statistics of EDA normalization data.

Figure 2. Skin electrical signal rate histogram.
4.2. HRV Data Analysis

In this experiment, the data were collected over a short period of time, and therefore frequency domain analysis was used to obtain more accurate analysis data. The frequency domain analysis mainly referred to the total power TP, high frequency power HF, low frequency power LF, and the equilibrium ratio LF/HF for heart rate variability.

In figure 3, the red curve records the change of the subject’s photovolumetric pulse signal. The PPG signal shows a regular repeating waveform with distinct peaks and troughs in the calm state, while the PPG signal shows other waveforms when the subject receives external stimuli. Depending on the marker points during the experiment, the HRV signal was also divided into several different signal fragments that were consistent with the EDA signal fragments. The energy values of this signal fragment are presented in the analysis results list, focusing on the four values of TP, LF, HF, and LF/HF, which are summarized for subsequent analysis.

![Figure 3. PPG signal curve and the result interface of HRV signal analysis.](image)

The data on heart rate variability of 30 subjects at the four interfacial transparency levels of 20% to 80% were compiled to obtain the total power TP, high frequency power HF, low frequency power LF, and equilibrium ratio LF/HF of the subjects (table 5). LF/HF reflects the antagonism between sympathetic and parasympathetic nerves, and this antagonism should be in a weakened state when a person is in a comfortable state, therefore, in the investigation of the antagonism between the sympathetic and parasympathetic nerves that makes a person perceive comfort, the results of LF/HF are listed here. Transparency should be focused on the interface transparency with a lower LF/HF value change rate. The trend of LF/HF equilibrium ratios of subjects of different genders under different interface transparency conditions was almost the same, so the combined rate of change of 30 subjects was used to measure the subjects’ perceived comfort level. A histogram of the change in perception under different transparency conditions was plotted according to the values (figure 4). The LF/HF equilibrium ratio change rate was lower and the antagonistic effect was weaker at 80% and 40% of the interface transparency, whereas the LF/HF equilibrium ratio change rate was stronger and the antagonistic effect was significant at 60% and 20% of the interface transparency. It may have changed significantly.

|                      | Baseline | Interface Transparency |
|----------------------|----------|------------------------|
|                      |          | 80%        | 60%        | 40%        | 20%        |
| Female Avg.          | 0.217    | 0.240      | 0.157      | 0.182      | 0.204      |
| Male Avg.            | 0.205    | 0.206      | 0.195      | 0.226      | 0.168      |
| Combined average     | 0.212    | 0.225      | 0.173      | 0.201      | 0.188      |
| Variance             | 0.012    | 0.018      | 0.008      | 0.015      | 0.10       |
| Rate of change       | ---      | 6.32%      | 18.08%     | 4.86%      | 11.0%      |
Combining the EDA and HRV data of the 30 subjects, it can be inferred that under the four interface transparency conditions, the subjects’ visual perception comfort is higher when the interface transparency is 40% and less comfortable when the street interface is 20% transparent. In order to ensure the reliability of the results, the subjective comfort scores can be further verified in conjunction with the results of the subjects’ subjective comfort scores (figure 5).

4.3. Analysis of Subjective Questionnaire Results
In this experiment, a subjective questionnaire was administered to the participants at the end of the human factors experiment. After observing all four video clips with different interface transparency, the participants were instructed to rank the clips according to the degree of visual perceived comfort from highest to lowest. The ranking was divided into four levels, with level 1 being the most comfortable and level 4 being the least comfortable, and each participant’s choice was assigned a score according to the ranking: level 1-4, level 2-3, level 3-2, level 4-1. Statistics were conducted and the scores were as follows (table 6).

![Figure 4. Histogram of HRV signal balance ratio change rate.](image1)

![Figure 5. Interface transparency subjective score bar chart.](image2)

Table 6. Interface transparency subjective ranking average score.

| Interface Transparency | 80% | 60% | 40% | 20% |
|------------------------|-----|-----|-----|-----|
| Female                 | 2.47| 2.82| 2.94| 1.64|
| Male                   | 2.15| 2.53| 3.46| 1.92|
| General                | 2.33| 2.70| 3.16| 1.76|

According to the available scoring results, the mean of the subjective scores for each of the four types of interface transparency was calculated, and the scores for each gender were also calculated.

From the subjective ranking of the 13 male and 17 female subjects, it can be seen that the scoring order of the four types of interface transparency is 40%>60%>80%>20%. The female subjects showed a flat and even trend in scoring the first three groups of interface transparency, and showed a significant discomfort for the 20% of the interface transparency; the male subjects showed a significant preference for the 40% of the interface transparency, and the subjective scoring results showed a significant upward trend. However, when comparing the two groups together, although the differences in the scores for the individual interface transparency values were significant, the overall preference trend was the same, with an increasing trend from 80% to 40% and a sudden decrease at 20%.

4.4. Interface Transparency Perception Measurement Results
After translational analysis of the EDA and HRV data of the 30 subjects, it was found that the average level of the EDA data was highest when the interface transparency was 40% and the LF/HF data did not fluctuate much compared to the baseline condition. Based on the subjective scores of the 30
subjects, it can be concluded that the subjective score of visual perception is highest when the interface transparency is 40%, and lowest when the interface transparency is 20%, which is consistent with the results analyzed from the subjects' physiological signal data. Based on the above data, it can be concluded that under the four transparency scenarios in this experiment, when the interface transparency reaches 40%, users are most comfortable with the visual perception of the living commercial street interface. Summarizing the characteristics of the street interface with 40% transparency, we can see that the third type of interface dominates in this experiment, i.e., advertising glass windows with product scenery, indicating that it is easier for people to perceive the interface layout with transparent glass doors. At the same time, it should be noted that the perception measurement results are based on the experimental conditions and are limited to a certain extent because the laboratory environment cannot simulate the changes of seasons, weather and geographical conditions.

5. Conclusion
This study uses Sketchup software to simulate and construct the interface transparency on the space side of the northern lifestyle commercial street, getting rid of the time and place constraints and providing experimental samples for human factors experiments. Using EDA and PPG physiological sensing technology and relying on ErgoLAB experimental platform for data collection and analysis, and combining with a subjective questionnaire, we obtained the subjects' visual perception preferences for interface transparency and summarized the composition elements and layout characteristics of transparent interfaces under visual comfort conditions.

The extraction and study of the interface design elements of the commercial side of the North Life Bank is the prerequisite for quantifying the perceptual design of the street space, which provides the basis for exploring the relationship between the morphological design elements and the perceptual imagery. Such methods are applicable to both interior design and product design. With the increasing maturity of human factors experimental techniques, and the integration with other virtual reality and eye movement analysis techniques, this method of extracting and researching design elements will be more complete.

Acknowledgments
The research was funded by the 2018 Talent Project: "Xingliao Talent Program" distinguished professor Project, "Research on the Design Index of Old-age Buildings under the Measurement of New Technology Perception Comfort" (tpjs2019001).

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