

Effects of Different Visual Styles on Elderly Users' Interaction Behavior in Smart Sofa Interfaces

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The usability of wood-based smart furniture interfaces for elderly users remains a critical challenge in aging-in-place solutions. This study aims to explore the most effective visual presentation styles of sofa illustrations in the smart sofa mobile app interface, with the goal of reducing cognitive load and enhancing the interaction experience for elderly users. To achieve this, we evaluated the cognitive responses of elderly users to different visual presentation styles through eye-tracking experiments and correctness analysis. As the results show, the four visual presentation styles exhibited comparable attention levels but diverged in concentration patterns. A 3D modeling schematic focused on peripheral interface areas, whereas physical product schematic and planar schematic emphasized hardware components. Abstract styles increased cognitive resource allocation and prolonged information processing. Pupil diameter and time to first fix (TTFF) data indicated that the 3D schematic imposed the lowest cognitive difficulty and pressure, while physical product schematic and 3D modeling schematic provided superior real-time feedback clarity. Therefore, wood-based smart sofa interface design should address elderly users' needs by optimizing visual presentation styles, reducing cognitive load and stress, and improving attention. Future research should explore multi-channel human-computer interaction to support smart sofa adoption for aging in place.

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INTRODUCTION

China, due to its enormous size and an aging rate of over 14.7%, has nearly progressed into a deep aging society (Li *et al.* 2024), accounting for 18% of the world's population in 2019, with 164.5 million Chinese citizens aged 65 and over and 26 million aged 80 and over (Fang *et al.* 2020). Due to the ageing population, there is an urgent market demand for comfortable, humanized, and specialized home furnishing products for the elderly (Zhou *et al.* 2022d). Intelligent ageing is gradually gaining attention, and smart homes provide a new solution for the elderly to age in place. As the core interactive terminal of the smart home system, the smart sofa has been upgraded from a traditional seat to an intelligent platform that integrates environmental perception, human-computer interaction and health management. Currently, mature products are generally equipped with electric adjustment systems, multimodal interactive interfaces (such as voice/touch control) and health monitoring modules (Frischer *et al.* 2020). Its functional design

accurately adapts to the core pain points of the elderly group, such as decreased mobility and weakened muscle strength due to physiological function decline (Merilampi *et al.* 2020). Therefore, the smart sofa is expected to become a key technical carrier for improving life autonomy in home-based elderly care scenarios.

Currently, smart sofa technology is continuously improving elderly-friendly design and functional integration, and the research focus is gradually shifting from hardware innovation to interaction optimization (Yu *et al.* 2024). Although the modular structure has improved the acceptance of elderly users, the information presentation mode and cognitive adaptability of the smart terminal interface, which is the core interactive medium, still lack systematic research. Given that the elderly generally have experience in using touch screens, how to optimize the presentation method and reduce cognitive load and pressure has become a key direction for improving user experience (Leme *et al.* 2014).

Research on ageing in the field of interaction design has received extensive attention internationally, and numerous studies have been devoted to meeting the needs of older adults and enhancing their user experience. Areas of user concern, including visual appearance, functionality, affordability, privacy issues, and interaction complexity, were summarised in the study by Lorenz and Oppermann (2009). Modern human-computer interaction interfaces, represented by virtual controls, such as symbols, icons, and graphics, are gradually replacing physical controls, such as buttons, knobs, and switches as the dominant medium of user-system interaction (Liu *et al.* 2023).

The visual presentation style within an interface plays a critical role in influencing the user experience and interaction efficiency of elderly users. Studies have shown that 3D interfaces can enhance older adults' understanding of spatial positions and movements, thereby improving their accuracy in self-assessment and their ability to operate independently (Hamm *et al.* 2017). Other researchers have found that clear visual presentation improves interaction efficiency for elderly users. They prioritize iconic information, and simplifying operations enhances the ease of use (Huang *et al.* 2022). Zhou *et al.* showed that simple line-style buttons perform best (Zhou *et al.* 2022a). Older adults prefer anthropomorphic icons for better information retrieval (Chen *et al.* 2020) and find them more usable and aesthetically pleasing (Urbano *et al.* 2022). Moving images help teach interactive gestures (Cabreira and Hwang 2018). Reddy *et al.* found that older users perform better with text-focused interfaces (Reddy *et al.* 2020). Balancing graphics and text, and reducing clutter further enhances user experience (Zhou *et al.* 2022b).

Eye-tracking technology has become a key focus in interactive information retrieval (Yu *et al.* 2022), revealing user motivations, cognitive psychology, and attention distribution (Ninaus *et al.* 2020) while assessing search interface usability. Zhou *et al.* used eye-tracking to identify design features enhancing usability for older adults, such as structured layouts, larger icons, lower information density, and context-aware colors (Zhou *et al.* 2022c). Lee *et al.* proposed a non-wearable eye-tracking method for multimedia interaction on large displays (Lee *et al.* 2013).

Given humanity's evolutionary reliance on three-dimensional vision, this study proposes the following hypothesis: three-dimensional presentation methods may inherently offer humans a faster, lower-cognitive-load advantage in understanding information, particularly for elderly populations prone to cognitive overload. To test this hypothesis, this study investigated four visual presentation styles to figure out its impact on the cognition of the elderly. These four different visual presentation styles refer to visual presentation styles of sofa illustrations in the smart sofa mobile app interface. By setting different visual presentation styles for sofa illustrations, cognitive response data from

elderly users were recorded to provide empirical references for the design of sofa chair control interfaces for the elderly. This study addresses the following questions:

(1) Under different visual presentation styles of sofa illustrations in the smart sofa mobile app interface, how do elderly users' attention levels and attention distribution vary across different presentation styles?

(2) For the visual presentation styles of sofa illustrations, what are the respective effects of different styles on elderly users' cognitive abilities? Which presentation style most effectively reduces cognitive load and enhances cognitive performance among elderly users?

MATERIALS AND METHODS

Participants

Individuals aged 65 and above are typically classified as "older adults" (Lee *et al.* 2018; Min *et al.* 2023). A total of 16 older adults participated in this experiment, a sample size comparable to that used in previous eye-tracking studies (Chen 2019; Serou *et al.* 2020; Zhou *et al.* 2022c). Participants ranged in age from 65 to 72, with a mean age of 67.15 years, and an equal gender distribution (1:1). They had secondary education or higher, were interested in sofa chairs, had basic smartphone skills, and showed no color vision issues or cognitive impairment, with a MoCA score of 27.7, ensuring a clear understanding of the experimental process (Trzepacz *et al.* 2015).

Experimental Equipment

The experimental setup consists of two devices: (a) a 6.1-inch smartphone with 1080 × 2520 pixel resolution running Inkblate 1.2.5 software for stimulus presentation, and it is fixed on a mobile phone holder; (b) the Tobii Pro Glasses 3 eye-tracker manufactured by Tobii Sweden, widely applied in ergonomics and psychology research. The eye-tracker includes a head-mounted module capturing eye movements, scene video, and ambient audio alongside a compact recorder storing data on SD cards without restricting participant mobility, thereby simulating real-world usage scenarios. Equipped with Tobii's proprietary 3D eye model and dual eye tracking sensors per eye, the system achieves 100 Hz sampling frequency, 0.4° gaze accuracy, single-point calibration, and stable binocular pupil measurements. In addition, the image processing software used was Adobe Photoshop CS6 version 13.0, developed by Adobe Inc. of the United States; the grayscale analysis used the HALCON 19.11 software developed by MVTec of Germany, and the data analysis software used was IBM SPSS Statistics 27, designed by IBM (Armonk, NY, USA).

Experimental Material

We first conducted market research and user interviews. Based on the results, a best-selling sofa model was chosen as the sample. Then, we created four types of standardized control interface illustrations. These included: (a) a physical product schematic, (b) a 3D modeling schematic, (c) a planar schematic, and (d) a linear schematic. These four types represent a gradient from low to high in terms of visual abstraction.

Each schematic style conveys distinct product states, directly influencing users' operational judgments. Physical product schematic and 3D modeling schematic simulate objects through dimensional realism, emphasizing hierarchical details. The former aligns

closest to users' mental models of product form, yet risks obscuring dynamic details; the latter empowers designer-controlled visualization of operational states. Planar schematic employs minimalist abstraction requiring user mental transformation, while Linear schematic balances abstraction with enhanced detail disclosure. Experimental material interface elements include product presentation, icons, text, buttons, *etc.* (Fig. 1).

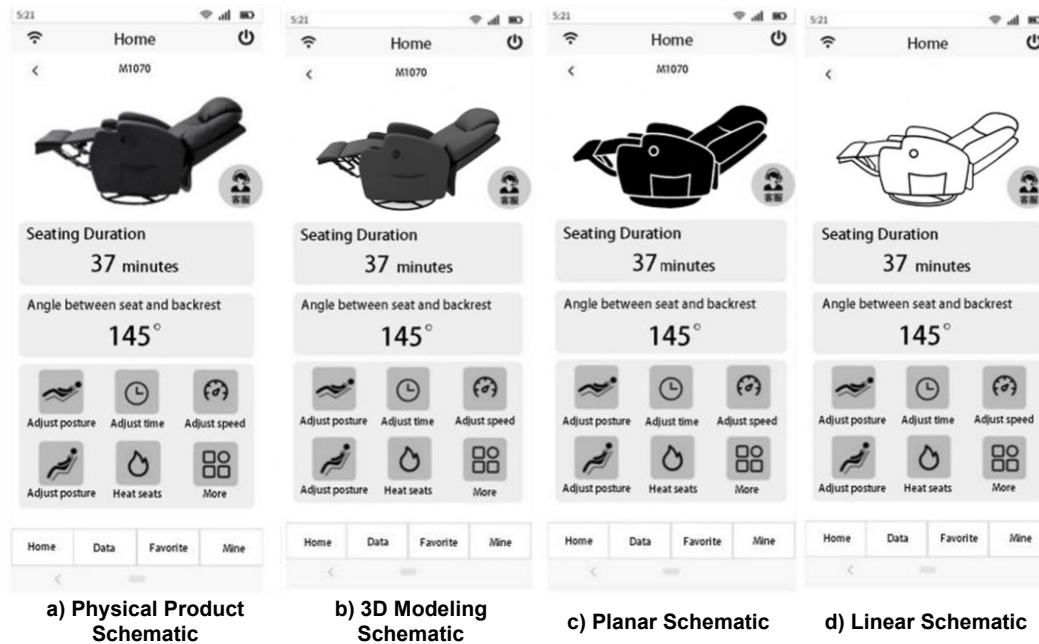


Fig. 1. Four ways to present experimental materials

Procedure

The study primarily employed a combination of eye-tracking experiments and accuracy analysis. The former revealed the attention distribution and cognitive load of elderly users toward the sofa control interface icons, while the latter reflected users' cognitive accuracy. This combination of objective and subjective methods helps mitigate the bias inherent in single-method experiments. It also enables a more thorough and accurate assessment of cognitive function in the elderly.

In the eye-tracking experiment, two metrics were used: pupil diameter and time to first fix (TTFF). Pupil diameter is a key indicator of cognitive resource allocation and mental load during visual cognitive processing; a larger pupil diameter indicates greater mental load (Wei and Steenbergen 2018). TTFF refers to the time it takes for participants to focus on a specific area of interest (AOI) from the onset of the stimulus. TTFF can indicate bottom-up stimulus-driven search and top-down attention-driven search (Rebollar *et al.* 2015). TTFF is a highly valuable metric in eye-tracking studies, primarily used to assess the efficiency of identifying interface areas and confirm the attractiveness of target visuals (Wang *et al.* 2025).

Accuracy is a direct indicator of cognitive performance levels, reflecting the accuracy of participants' recognition of targets (Jaeggi *et al.* 2025). To accurately analyze users' cognitive levels regarding the smart sofa control interface's sofa illustrations, the accuracy analysis included three questions: identifying the current state of the seat, perceiving the ease of standing up, and estimating the angle of the seatback. These

questions were selected based on common interaction tasks older users perform when operating adjustable smart sofas, aiming to assess their comprehension of functional status and spatial configuration. The first two questions were presented as multiple-choice items, while the third required estimating within a $\pm 15^\circ$ range.

As shown in Figure 2, participants provided demographic information and signed a safety statement before the test. The experiment was conducted in two separate parts: the eye-tracking experiment and the accuracy analysis experiment, ensuring that the only variable in the eye-tracking experiment was the presentation style of the sofa illustration in the smartphone interface. Users first participated in the eye-tracking experiment. Elderly participants sat on a sofa chair wearing an eye-tracking device, with a fixed-height floor-standing smartphone stand placed in front to secure the smartphone, ensuring consistent distance between each participant and the smartphone. Each participant explored the pages independently, and the order of presentation for the four pages was randomized to minimize the cognitive impact of the order in which images appeared. Subsequently, users conducted the accuracy analysis experiment, where they were required to answer questions based on the state of the sofa illustrations presented on the interface. To distinguish perceptual judgments from environmental factors, the interface state occasionally deviated from the actual physical configuration.

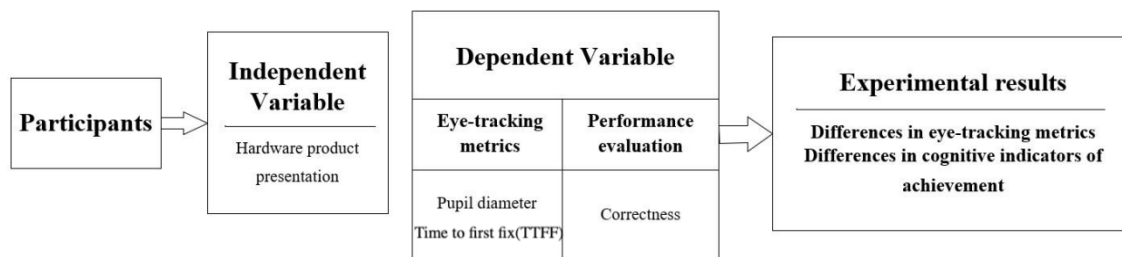


Fig. 2. Experimental framework

RESULTS

Valid data samples were obtained from 14 of the 16 experimental subjects for final exploratory analysis. The empirical effects of the different materials were measured by heatmap, pupil diameter, time to first gaze, and correctness of the questions answered by the subjects, respectively.

Eye-tracking Metric Statistical Results

Heatmap is a data visualization technique used to display each data cell's relative size and distribution in a two-dimensional data matrix. The AOI statistics as functional metrics in an eye-tracking system are realised by selecting the target area and extracting some eye-tracking metrics for statistical analysis (Wang *et al.* 2023). Through analysing the spatial and temporal distribution characteristics of eye movement data in the form of a heatmap, it is possible to represent the subjects' attention to different AOIs through the difference of colour. The gradation from red to yellow to green and finally to purple indicates the degree of concentration of attention, with the red colour indicating the highest number of eye movements, which suggests that the subjects pay more attention to the region; the yellow colour is second to the red colour, which indicates the relatively high

number of eye movements; the green colour represents the region that has been watched a small number of times. The purple colour indicates that the AOI is of average concern to the subjects; the purple colour indicates that the AOI is of minimal regard to the subjects; and the blank area means that the AOI has not attracted the attention of the subjects at all. Figure 3 shows some of the heat maps captured in this experiment, which have been processed by Photoshop for the environment outside the interface observed by the eye-tracker, leaving only the content of the interface.

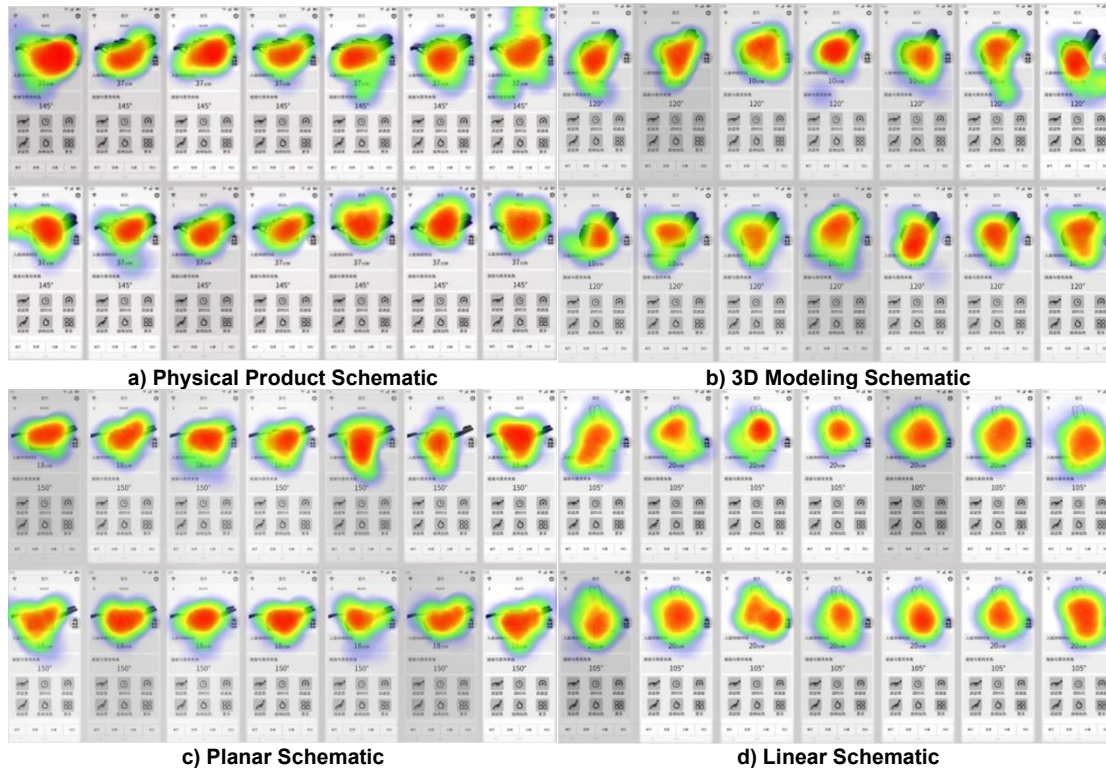


Fig. 3. Thermogram comparison

To further obtain the picture information of the heat map, the experiment adopts the greyscale histogram feature extraction method. Firstly, the background of the heat map is separated (Fig. 4), and then the heat map after the background separation is analysed in greyscale using HALCON 19.11, and the greyscale histogram data is generated as shown in Table 1.

Experimental samples were categorized into four groups (A, B, C, D), with 56 grayscale histogram datasets collected. The analytical metrics comprised two components: the number of peak grayscale pixels and the percentage coverage of the red zone. Data processing followed standardized protocols: if a peak was detected at grayscale value 255, the secondary peak was selected while discarding the primary peak at 255. Post-processing analysis revealed bimodal distribution characteristics across all datasets, with peak grayscale values stabilizing at 166. Subsequent validation confirmed that grayscale 166 corresponded to the green zone's grayscale range.

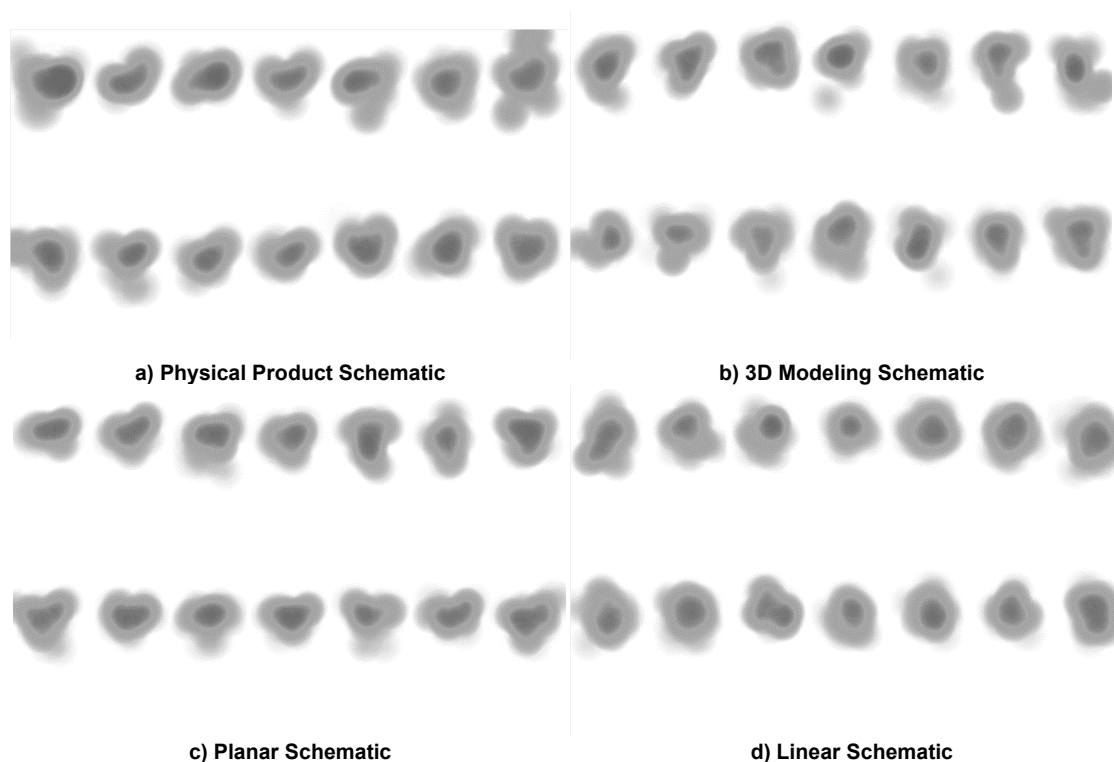


Fig. 4. Heat map after background separation

Table 1. Gray Histogram and Its Value

Number	Number of Peak Greyscale Pixels	Percentage of Red Zone Coverage (%)	Number	Number of Peak Greyscale Pixels	Percentage of Red Zone Coverage (%)
A01	1642	14.19	C01	1517	8.74
A02	1532	10.17	C02	1747	9.50
A03	1701	11.75	C03	1891	10.06
A04	1504	9.36	C04	1764	8.98
A05	1686	10.16	C05	1929	10.81
A06	1752	9.97	C06	1753	7.92
A07	1579	15.31	C07	1634	11.17
A08	2036	11.72	C08	2067	10.57
A09	1477	8.43	C09	1556	9.48
A10	1416	8.69	C10	1701	8.59
A11	1455	8.29	C11	1592	9.26
A12	1642	11.38	C12	1776	7.60
A13	1500	10.45	C13	1679	8.92
A14	1707	11.77	C14	1839	10.79
B01	2100	9.74	D01	2318	12.02
B02	1859	9.76	D02	2077	8.61
B03	2056	11.13	D03	2158	8.36
B04	1532	7.73	D04	1476	7.35
B05	1813	7.90	D05	2009	10.29
B06	2400	9.64	D06	1953	11.16
B07	2315	9.50	D07	2332	11.62
B08	1792	7.44	D08	2264	9.84
B09	2458	8.75	D09	2025	10.85

B10	2182	8.79	D10	1835	10.92
B11	2544	11.16	D11	1987	8.31
B12	1560	9.05	D12	1676	8.77
B13	1727	8.63	D13	1674	8.33
B14	2242	11.41	D14	1867	11.61

The peak value of the greyscale histogram and the percentage of the number of pixels in the red zone range were used as statistical indicators. The results were subjected to a one-way analysis of variance (ANOVA) to determine whether the differences in the visual presentation styles differed significantly under the dimensions of the heat map analysis. The results obtained from the calculations using IBM SPSS Statistics 27 are shown in Table 2.

Table 2. ANOVA Verification of the Rendering Style on Each Factor

Presentation Styles	Number of Peak Greyscale Pixels		Percentage of Red Zone Coverage	
	Averages	Standard Deviation	Averages	Standard Deviation
A	1616.36	160.84	10.83	2.06
B	2041.43	331.78	9.33	1.26
C	1746.07	151.60	9.46	1.10
D	1975.07	253.75	9.86	1.54
F	9.83		2.75	
LSD	B > A, C, D			

The analysis shows a significant difference in the number of peak grey pixels ($F = 9.83$, $P < 0.001$) but no significant difference in the percentage of the red zone range ($F = 2.75$, $P = 0.052 > 0.05$). Overall, there's no significant difference in attention levels across the four visual presentation styles. *Post hoc* LSD tests indicate that the 3D modeling schematic has significantly more peak grey pixels, suggesting a broader scope of attention and more focus on other AOIs.

Combined with the heat map analysis, for the interface where the physical product schematic and the Planar schematic are located, the subjects mainly pay attention to the product presentation illustration of the sofa and chair and pay less attention to the other AOIs. For the 3D modeling schematic, the subjects browse through the illustration and pay slight attention to the textual information and the button information at the same time. The heat map of the linear schematic has a more even distribution.

Pupil Diameter Analysis

This study analyzed mean pupil diameters from both eyes, conducting an ANOVA Chi-square test that yielded a P-value of 0.095, exceeding the 0.05 significance threshold and thus meeting ANOVA assumptions for further analysis.

As shown in Fig. 5, comparative analysis of pupil diameters across presentation styles revealed distinct trends. The 3D modeling schematic induced significantly smaller pupil diameters than other styles, while the linear schematic triggered the largest. *Post hoc* LSD tests were applied to evaluate style-specific differences. Results demonstrated significant heterogeneity in pupil diameter variations among all four styles: physical product schematic, 3D modeling schematic, planar schematic, and linear schematic (Table 3). Reduced pupil diameters under the 3D modeling schematic indicate superior cognitive efficiency, correlating with lower cognitive load and operational complexity when conveying equivalent information.

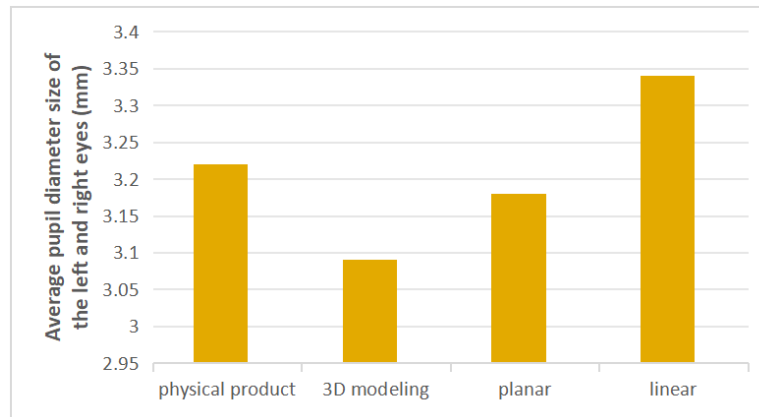


Fig. 5. Visual presentation style pupil diameter contrast

Table 3. Multiple Comparison Tests of Pupil Diameter Presented in a Pattern LSD Posteriorly

(I) Presentation Styles	(J) Presentation Styles	(I - J) Mean Value Difference	Standard Error	Significance Level	95% Confidence Intervals	
					Lower Bound	Upper Bound
3D Modeling Schematic	Planar Schematic	-0.1091*	0.00216	0.000	-0.1136	-0.1046
	Physical Product Schematic	0.0133*	0.00241	0.000	0.0022	0.0185
	Linear Schematic	-0.0061*	0.00239	0.037	-0.0098	-0.0024
Planar Schematic	3D Modeling Schematic	0.1091*	0.00216	0.000	0.1046	0.1136
	Physical Product Schematic	-0.1209*	0.00237	0.000	-0.1241	-0.1177
	Linear Schematic	-0.0114*	0.00242	0.000	-0.0149	-0.0079
Physical Product Schematic	3D Modeling Schematic	-0.0133*	0.00241	0.000	-0.0185	-0.0022
	Planar Schematic	0.1209*	0.00237	0.000	0.1177	0.1241
	Linear Schematic	-0.1045*	0.00279	0.000	-0.1076	-0.1014
Linear Schematic	3D Modeling Schematic	0.0061*	0.00239	0.037	0.0024	0.0098
	Planar Schematic	0.0114*	0.00242	0.000	0.0079	0.0149
	Physical Product Schematic	0.1045*	0.00279	0.000	0.1014	0.1076

* Indicates a significance level of 0.05 for the difference in means

Time to First Fix Analysis

The ANOVA Chi-square test for TTFF ($P = 0.135$, $P > 0.05$) confirms the validity of the significance assumption, allowing the data to proceed to the next ANOVA step. Figure 6 shows that the line schematic diagram results in significantly longer time

compared to other presentation styles, consistent with changes in pupil diameter. The LSD tests, shown in Table 4, reveal significant differences in TTFF across physical product schematic, 3D modeling schematic, and planar schematic. Among them, the 3D modeling schematic shows shorter TTFF.

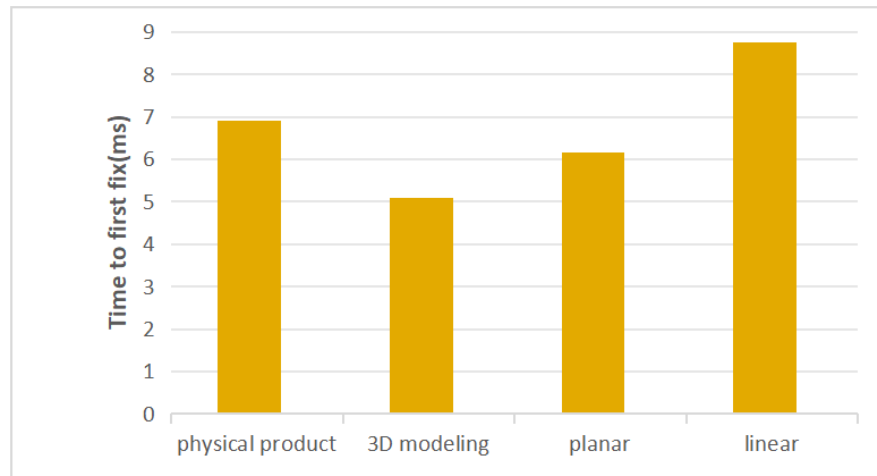


Fig. 6. Visual presentation style time to first fix comparison

Table 4. Render Style of Time to First Fix LSD after Multiple Comparison Tests

(I) Presentation Styles	(J) Presentation Styles	(I – J) Mean Value Difference	Standard Error	Significance Level	95% Confidence Intervals	
					Lower Bound	Upper Bound
3D Modeling Schematic	Planar Schematic	-2.39308*	0.50507	0.000	-3.7668	– 1.0194
	Physical Product Schematic	-0.57112*	0.50523	0.143	-2.0963	0.9541
	Linear Schematic	0.02807*	0.50549	0.000	-1.2547	1.3109
Planar Schematic	3D Modeling Schematic	2.39308*	0.50507	0.000	1.0194	3.7668
	Physical Product Schematic	0.56944*	0.50517	0.000	-0.4609	1.5997
	Linear Schematic	-0.55374*	0.50519	0.000	-1.7264	0.6189
Physical Product Schematic	3D Modeling Schematic	0.57112*	0.50523	0.143	-0.9541	2.0963
	Planar Schematic	-0.56944*	0.50517	0.000	-1.5997	0.4609
	Linear Schematic	-1.35972*	0.50512	0.000	-2.3714	– 0.3481
Linear Schematic	3D Modeling Schematic	-0.02807*	0.50549	0.000	-1.3109	1.2547
	Planar Schematic	0.55374*	0.50519	0.000	-0.6189	1.7264
	Physical Product Schematic	1.35972*	0.50512	0.000	0.34811	2.3714

* Indicates a significance level of 0.05 for the difference in means

Correctness Analysis

For the correctness analysis, three questions were included: judging the seat's current state, assessing the appropriateness of getting up based on the user's perception, and evaluating the angle between the seat surface and backrest. The first two were choice questions, while the last question focused on determining whether the subject could generate accurate perceptions of the experimental material by observing the display style.

As shown in Fig. 7, the 3D modeling schematic best aligned with the elderly group's cognition and perception of actual objects, followed by the physical product schematic, while the linear schematic performed relatively poorly. The correctness rates across the four visual presentation styles were consistent with the average correctness rates for the three questions.

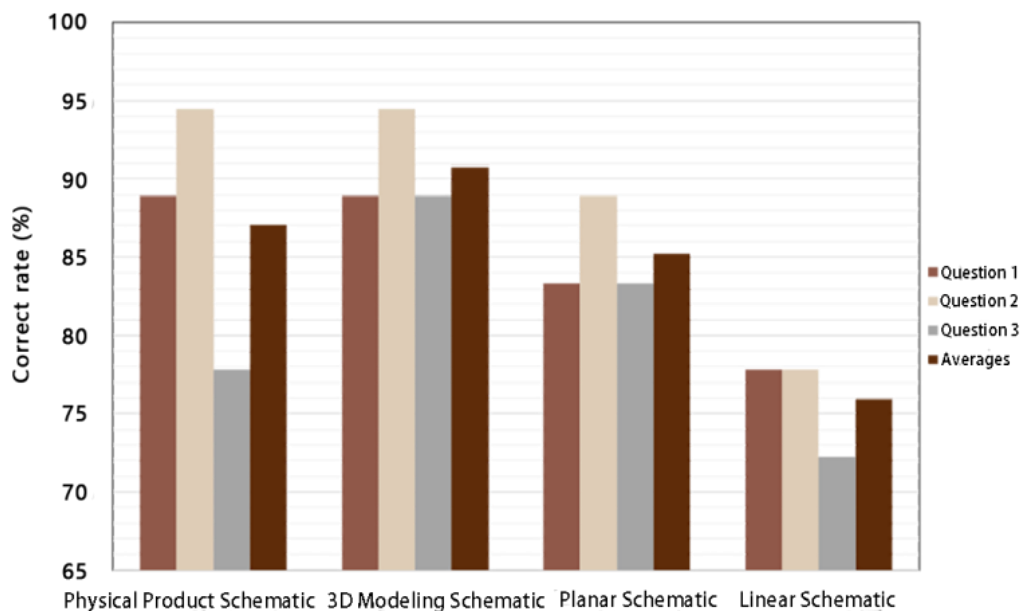


Fig. 7. Descriptive statistics of correct rate of problem

DISCUSSION

This paper uses eye movement experiments to study how four visual presentation styles of sofa illustrations affect elderly people's cognitive performance. The styles include physical product schematic, 3D modeling schematic, planar schematic, and linear schematic. Through heat maps, pupil diameter, and TTFF, it analyzes the spatial and temporal distribution of eye movement data, measuring cognitive resource allocation and cognitive load. Finally, the results are validated by combining them with the correctness of the question responses.

Attention Span and Distribution of Attention Among Older Adults

Analyzing eye movement heat maps, this study found no significant difference in users' overall attention across the four visual presentation styles of sofa illustrations in the smart sofa mobile app interface. However, visual presentation style strongly affects attention distribution. The physical product schematic, with more detailed information, requires longer viewing time and makes information extraction harder, reducing attention

to other areas (AOIs). In contrast, the 3D modeling schematic broadens attention range, promoting balanced attention and improving information extraction efficiency. Physical product schematic and planar schematic presentations make users focus more on hardware schematics.

As shown in Figure 6 and Table 4, time to first fix (TTFF) for 3D modeling diagrams is the shortest among the four visual presentation styles. This indicates that 3D modeling diagrams have stronger visual appeal compared to other styles. One possible explanation is that this style achieves a good balance between realism and simplicity, enabling users to quickly identify key information areas within the interface and thus focus their gaze more rapidly. This also suggests that 3D modeling diagrams have a higher priority in page optimization design, particularly for enhancing interface recognition efficiency among elderly users.

Cognitive Load and Cognitive Performance in Older Adults

This study found that pupil diameter increases as the level of detail and abstraction in the presentation method increases. Simplified and abstract presentation styles require more cognitive resources, making it difficult for users to establish a mental connection between the visual presentation and the physical product. Increased task difficulty leads to larger pupil diameters (Biondi *et al.* 2023; Gorin *et al.* 2024), while an increase in visual details unrelated to the task increases interference and prolongs processing time. It is worth noting that the histogram of pupil diameter is very similar to that of TTFF. Given that pupil diameter is positively correlated with cognitive load, this similarity suggests a potential positive correlation between TTFF and cognitive load as well. In a 2024 study by Das *et al.*, under the Static Highlight condition, high cognitive load significantly prolonged TTFF compared to no-load and low-load conditions, with the differences being statistically significant (Das *et al.* 2024). Similarly, Miljković and Sodnik (2024) found that cognitive distraction—such as performing a secondary task under high cognitive load—led to delayed TTFF in healthy individuals. However, the specific relationship between TTFF and cognitive load still requires further investigation in future studies.

According to the descriptive statistics results of the third question correctness feedback, it was found that after observing the physical product schematic, the subjects had higher accuracy in answering questions one and two. However, the accuracy of their responses to question three was lower than the cognitive level of the planar schematic. It may be because although the physical product schematic is the most suitable for the actual, the actual picture is too complex to show the details of the changes, and there are more accessories, which interfered with the subjects for the seat surface and backrest angle of the judgment. In contrast, 3D modeling schematic of the three questions have a higher rate of correctness, with the highest average rate of correctness, which can be seen that 3D modeling schematic are more accessible to show the details of the subjects and provide better feedback on the current information of the product.

Based on the above discussion, the following conclusions can be drawn: Three-dimensional modeling diagrams have the characteristic of being vivid and intuitive, which is more conducive to the cognitive processing of interface information by test subjects. This can improve the acceptance level and cognitive performance of the elderly population, thereby validating the hypothesis we proposed at the beginning. This may be because physical diagrams contain too many details, while line diagrams and surface diagrams are too abstract. In contrast, three-dimensional modeling diagrams, with their balanced level of detail and abstraction, maximize cognitive performance in the elderly.

Deficiencies and Prospects

This study has two main limitations. First, the small sample size limits the ability to fully reflect cognitive issues. Second, pupil diameter and TTFF in eye tracking tests do not accurately represent cognitive state. These measures are also affected by factors such as emotional state and user preferences. Future research should explore these issues further.

As natural interaction interfaces emerge in the intelligent era, multi-channel human-computer interaction in smart sofa systems is gaining attention. Beyond vision and hearing, simulations of olfactory, tactile, and gustatory stimuli are being studied. For example, HairTouch by Lee *et al.* (2021) simulates different textures to enhance VR realism through haptic feedback; Silveira *et al.* (2023) explore heat and wind devices in interaction; and Hasheminia *et al.* (2023) show that musk aroma improves neural feedback training and attention. With technological advancement and the growing use of smart products, human-computer interaction will increasingly focus on user experience and cognitive load, aiming to optimize product design and improve cognitive performance and satisfaction through interdisciplinary research.

CONCLUSIONS

1. Although there was no significant difference in overall attention across the four styles, the 3D modeling schematic encouraged broader attention across the interface, while the physical and planar schematics focused attention on the hardware illustrations. In addition, in comparison with other visual styles, the 3D modeling schematic was more visually attractive within the page.
2. More abstract or detail-rich images required greater cognitive resources and longer processing time, whereas the 3D modeling schematic showed the lowest cognitive pressure. This also aligns with the hypothesis proposed at the beginning of the paper that three-dimensional graphics are more easily understood by humans.
3. By combining eye-tracking data and correctness analysis, it was confirmed that the 3D modeling schematic is most beneficial for cognitive processing among elderly users and should be prioritized in interface design.

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