

# Research on age-friendly interaction design for smart homes based on the long-term memory mapping model

Huirong Wang MSc Candidate<sup>a</sup>, Xuefei Liu MSc<sup>a,\*</sup>, Di Fang BS<sup>a</sup>, Sijie Lyu MSc Candidate<sup>a</sup>

<sup>a</sup>School of Design, Dalian Minzu University, Dalian, Liaoning Province, China

\*Corresponding author: 1755691227@qq.com

## Abstract

**Objective:** To address challenges faced by older adults in smart home interface operations, such as high cognitive load and symbol recognition difficulties, this study attempts to propose a preliminary age-friendly interaction design method based on the "Long-term Memory Mapping (LMM) model" and explore the potential value of nostalgic symbols in interface design.

**Method:** Through literature analysis and in-depth interviews, nostalgic symbols familiar to older adults were identified, and a five-layer LMM structural model was constructed. Retro-style icons with a 1980s aesthetic were designed. A within-subject controlled experiment was conducted with 15 older adults aged 60-75 to compare their performance between the nostalgic icon group and the modern flat icon group in terms of first-time recognition accuracy, task completion time, and error frequency.

**Results:** The nostalgic icon group performed better than the control group in first-time recognition accuracy, task completion time, and error frequency.

**Conclusion:** The preliminary findings of this exploratory study suggest that the use of nostalgic symbols is associated with the activation of long-term memory in older adults and may contribute to reduced cognitive load and improved operational efficiency. The LMM model offers some insights for the design of age-friendly interfaces in smart homes; however, the specific contribution of the "nostalgia effect" and its causal mechanisms still require further testing in future studies that strictly control for confounding variables.

Keywords: Long-term memory; Age-friendly interaction design; Smart home; Symbol cognition; Elderly user experience; Exploratory study

## INTRODUCTION

According to the 2023 National Development Bulletin on Aging Affairs released by the Ministry of Civil Affairs and the National Office on Aging, China's population aged 60 and above now accounts for 21.1% of the total population[1]. The elderly face a significant "digital divide" when integrating into contemporary society. When operating smart home interfaces, current designs featuring abstract symbols, complex steps, and small buttons increase cognitive load, hindering their ability to enjoy technological conveniences. Therefore, this study focuses on two core questions: How can interaction design effectively reduce the cognitive burden of smart home use for the elderly? How can nostalgic elements from long-term memory be leveraged in interface design to enhance usability? While existing research has attempted to reduce cognitive load through icon simplification and voice interaction, most studies have failed to systematically leverage nostalgic elements and cognitive strengths embedded in the long-term memory of the el-

derly. Therefore, this study proposes a preliminary theoretical framework for the "Long-Term Memory Mapping Model (LMM)," which aims to explore potential design pathways from "cognitive compensation" to "cognitive empowerment" through the mechanisms of symbolic cognition and nostalgia-induced arousal. It should be noted that this study is an exploratory effort intended to provide preliminary evidence and a theoretical foundation for subsequent, more rigorous causal testing.

## 2 CHALLENGES IN AGE-FRIENDLY DESIGN

### 2.1 Symbolic layer issues

Two problems exist at the symbolic layer in age-friendly design practice. Firstly, there exists a mismatch between the symbols currently in mainstream use and the physical symbols stored in the long-term memory of older adults. Second, cultural memory gaps impact their comprehension of interface content. Liu S noted that the "smart switch" icon in smart home products exhibits a highly abstract characteristic within cur-

rent user interface (UI) design styles. However, this abstract icon creates cognitive conflict with the physical image of old-fashioned pull-cord switches stored in their long-term memory [2]. Such symbolic mismatches confuse older adults when using smart devices, reducing their operational efficiency.

Another issue stems from the impact of cultural memory gaps. Many smart devices employ symbols from Western culture, with the hamburger menu being a prime example. These Western-derived symbols may lack intuitive recognizability for older adults, making it difficult for them to quickly grasp their meanings. Their life experiences mean they are more familiar with traditional, localized symbols. Such Westernized symbol designs clash with their memory experiences, creating cognitive barriers [3] and hindering the establishment of connections between the symbolic meaning and actual function of these icons.

## 2.2 Interaction layer issues

At the interaction level, older users face a disconnect between actions and intent in procedural memory: familiar past operations like pressing or rotating are difficult to directly apply to today's swipe-based gesture controls, resulting in a lack of familiar contextual cues during operation [2]. This shift in device interaction logic forces them to relearn new operational steps, significantly increasing their cognitive load.

The absence of contextual cues negatively impacts elderly users' experience. Many smart devices currently fail to organize functional entries according to elderly users' daily scenarios. For instance, time-related or routine-based entries like "Morning Exercise" or "Afternoon Rest" lack logical arrangement. Such design neglects the diverse usage needs across different scenarios, making it difficult for elderly users to quickly locate required functions [4].

## 2.3 Long-term memory layer issues

At the long-term memory level, the elderly primarily face challenges of insufficient emotional association and difficulty transferring prior experience. Current smart device interfaces lack elements that evoke nostalgia among seniors, and their operational methods conflict with long-established habits. Conversely, the visual characteristics and operational modes of classic devices like vintage radios and traditional televisions can trigger emotional resonance, thereby enhancing product acceptance and willingness to use [3]. For instance, incorporating the operational logic of "clockwise rotation increases volume, counterclockwise decreases

volume" from traditional devices into modern interface designs can reduce learning difficulty and enhance user satisfaction.

## 3 ANALYSIS OF THE CAUSES OF AGE-FRIENDLY DESIGN ISSUES

The underlying causes of the aforementioned issues in the symbolic, interactive, and memory layers can be categorized into three types: diminished information processing capacity due to cognitive aging mechanisms, symbolic comprehension barriers stemming from sociocultural disconnects, and systemic misalignment between technological offerings and the needs of elderly users. These will be analyzed sequentially below.

### 3.1 Mapping cognitive aging mechanisms to design variables

#### 3.1.1 Reduced bandwidth in the perception-symbol channel

One core mechanism of cognitive ageing is the general decline in information processing speed, manifested as reduced bandwidth in the conversion from sensory channels to symbolic representations. Ageing slows neural processing operations, triggering the "limited time mechanism" (where critical operations remain incomplete) and the "simultaneity mechanism" (where earlier processing results become obsolete by the time later processing is completed), which together impair cognitive function [5]. Changes in brain structure and function directly diminish the efficiency of perceptual information transmission, impacting the symbolic conversion process [6]. Older adults require longer periods to parse complex information, making them prone to omissions or misinterpretations, particularly in multitasking or high-time-pressure scenarios [7]. For instance, when elderly individuals attempt to log into an application or complete payment verification, the system-generated SMS verification code typically expires after 60 seconds. They must undertake a series of cognitive operations: reading the text message, memorising the six-digit code, switching back to the application, locating the input field, and accurately entering the code. Due to diminished information processing speed, any delay in a single step—such as misremembering or mistyping a digit—may prevent completion before the code expires. This necessitates re-triggering the SMS and restarting the entire process. This common predicament stems not from task complexity, but precisely from the "time-limited mechanism"—the critical operation (entering a valid code) remains "unfinished" because cognitive processing exceeds the system's designated time window.

## 3.1.2 *decline in working memory capacity and information architecture mismatch*

Declining working memory (WM) capacity is a core manifestation of age-related cognitive decline, directly impairing information buffering and integration abilities [7]. WM impairment causes imbalanced allocation of information processing resources. When complex information structures exceed WM capacity, older adults are prone to operational confusion or decision errors [8]. The mismatch between WM and information architecture triggers "cognitive mismatch," imposing additional mental load [9].

## 3.2 Sociocultural disconnect

### 3.2.1 *Technology iteration cycles vs. cultural memory half-life in the elderly*

Technology iteration cycles far outpace the cultural memory half-life of the elderly, making it difficult for their cognitive systems to synchronize updates. Rapidly proliferating technologies like mobile payments and smart device interfaces, abstract symbols of new technologies, and the weakening of traditional cultural carriers demand frequent adaptation to new interaction logics. Older adults rely on long-accumulated experiential symbols, with cognitive frameworks formed during industrial or pre-digital eras. Their preference for traditional hospitals over community institutions reflects dependence on familiar service models [10]. The temporal conflict between technological iteration and memory mechanisms further exacerbates long-term memory retrieval barriers. Home-based elderly care services often fail to adequately consider cultural habits, resulting in low utilization rates [11].

### 3.2.2 *Mismatch between globalized UI symbols and local elderly experiences*

Standardized interface symbols create semantic gaps with the lived experiences of local seniors. Internationally prevalent UI icons lack interpretability for rural or less-educated elderly populations. For instance, mismatched rural financial services stem from product designs that disregard farmers' actual cognitive levels [12]. Dialect vocabulary is excluded from interaction design, such as rural commercial insurance facing low acceptance due to obscure terminology [13]. Symbols familiar to the elderly remain untranslated into digital icons. While Song Dynasty porcelain patterns reflected contemporary sociocultural contexts, modern UI lacks such localized expressions [14].

## 3.3 Mismatch between technology supply and demand

### 3.3.1 *Commercial UI Standards Prioritize Universality Over Elderly-Specific Design*

Commercial design pursues economies of scale at the expense of elderly users' unique needs. Companies adopt one-size-fits-all design standards to reduce development costs. Complex process designs exceed elderly users' working memory capacity—for example, cumbersome home care service application procedures mismatch with their operational capabilities [12].

### 3.3.2 *insufficient data collection leaves personalized memory cues unaddressed*

The lack of data mining on individual life trajectories prevents technology from providing personalized memory assistance. Only basic operational data is collected, while emotional feedback is neglected. Critical memory cues like professional experiences and cultural preferences remain undigitized. In contrast to Song Dynasty porcelain patterns documenting social culture, modern technology fails to preserve individual memories [14].

## 4 EXISTING RESEARCH RESPONSES AND REMAINING GAPS

### 4.1 Symbol layer improvements

#### 4.1.1 *High-similarity icons and localized alternatives*

Current elderly symbol recognition systems primarily rely on explicit symbol recognition technologies, such as OCR text recognition and conventional icon detection algorithms. However, addressing only explicit symbol recognition results in a failure rate exceeding 60% for the localized adaptation of metaphorical functions [15]. The absence of an elderly symbol database covering urban-rural disparities has led to fragmented solutions.

#### 4.1.2 *multimodal symbol compensation*

Combining voice guidance with vibration feedback reduced form-filling errors among elderly users by 55%, with particularly significant effects in low-literacy groups [16]. Tactile feedback becomes ineffective in environments exceeding 65dB noise or for users with hand tremors [17]. No bone conduction alternatives exist for noisy environments, and multimodal combinations may increase cognitive load.

### 4.2 Interaction layer optimization

#### 4.2.1 *Gesture simplification and hierarchy reduction*

Replacing two-finger zooming with single-finger long press tripled map operation efficiency for elderly users [18]. However, this approach fails in payment verification interactions, forcing age-friendly interfaces to retain original workflows.

#### 4.2.2 *contextual navigation prototype*

The pharmacy navigation interface for location-based services (LBS) streamlines the process through a sequential flow of 'purchase medi-

cation → medication reminders → share with friends and family', reducing the operational pathway by 70% [19]. Failure to integrate with offline service networks results in a disconnect between digital and physical experiences.

## 4.3 Memory layer emotional engagement

### 4.3.1 Nostalgic content and sentiment measurement

Medical apps incorporating vintage photos or era-specific hits increased weekly retention among elderly users by 90%. However, after six months of repeated exposure, the emotional engagement effect declined to 27% of its initial value [21]. No algorithm was established for the frequency of nostalgic content delivery.

### 4.3.2 personalized memory cue generation

Through natural language processing (NLP) analysis of descriptive texts accompanying old photographs, the system automatically generates memory cues centered on the theme of 'family gatherings'. However, 87% of elderly participants declined to grant access permissions to their photo albums, resulting in insufficient data collection [21]. Memory reconstruction may trigger traumatic recollections, and the system lacks user control mechanisms.

## 5 RESEARCH DESIGN FOR AGE-FRIENDLY MEMORY

### 5.1 Overall approach

First, identify two major pain points in elderly smart home usage—abstract symbols and complex procedures—through literature review and interviews. Then construct a "Long-Term Memory Mapping Model" (LMM) and validate its effectiveness via a within-subjects experiment involving 15 participants aged 60–75.

### 5.2 Research methods

#### 5.2.1 Mixed methods

Literature analysis will first systematize cognitive aging and semiotics theories. Semi-structured in-depth interviews with 8 seniors will then identify nostalgic symbol needs. Finally, a small-sample (n=15) within-subjects experiment will compare nostalgic icons versus traditional icons across initial recognition accuracy, completion time, and error rates.

#### 5.2.2 Data sources and sampling strategy

G·Power estimated a minimum sample size of 12 participants. Accounting for a 20% attrition rate, 15 participants were recruited, covering educational backgrounds ranging from elementary to high school and varying levels of technological experience. Purposeful sampling ensured representativeness.

## 6. CONSTRUCTION OF THE LONG-TERM MEMORY MAPPING MODEL (LMM)

Research indicates that while older adults experience declines in working memory and processing speed, their long-term memory remains relatively intact and may even demonstrate advantages in certain contexts [22]. Therefore, activating long-term memory through nostalgic symbols can compensate for current cognitive resource deficits, achieving a 'memory compensation' effect. The LMM model is constructed precisely based on this mechanism.

### 6.1 LMM structural design

Drawing directly from the three research categories (cognitive aging, memory advantages, and symbolic nostalgia), the core pathway "nostalgic symbols → memory evocation → cognitive offloading" is derived. This forms the basis for constructing the five-layer LMM structure. The model comprises an input layer, symbol perception layer, memory retrieval layer, context matching layer, and action output layer: The input layer receives audiovisual symbols like icons and sound effects. After recognition by the symbol perception layer, nostalgic elements are activated, driving the memory retrieval layer to evoke past scene memories and emotional resonance. These are then mapped to the current interface context, guiding the action output layer to complete operations. The model's value lies in demonstrating the practical efficacy of memory mining in alleviating cognitive burden for the elderly, while providing theoretical foundations and practical guidance for age-friendly design (as shown in *Figure 1*).

### 6.2 Model hypotheses

H1: There is a positive correlation between the presentation of nostalgic symbols in the interface and the degree of activation of situational and semantic memory among older users.

H2: The degree of memory activation is negatively correlated with task cognitive load; that is, stronger memory recall is associated with lower error rates and shorter task completion times.

### 6.3 Summary

The LMM model is grounded in the "cognitive aging—memory advantage—symbolic trigger" triad theory. It translates the hypothetical mechanism of "nostalgic symbols → memory recall → cognitive load reduction" into a five-layer structure and proposes two testable hypotheses regarding their interrelationships. This framework attempts to bridge the gap between long-term memory research and interface design, providing an operational pathway and an evaluative foundation for the

# Age-friendly interaction design for smart homes

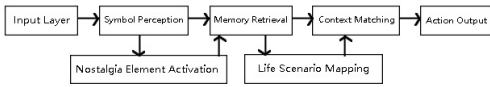


Figure 1. Long-term memory mapping model structure diagram (image designed by the author)

preliminary experimental validation of nostalgic icons in this study.

## 7. LMM-BASED DESIGN PRACTICES FOR AGE-FRIENDLY INTERFACES

### 7.1 Design goals and principles

By deeply integrating the long-term memory characteristics of older adults with pain points in smart home usage, we will optimize three dimensions: icons, functional navigation, and feedback.

#### 7.1.1 Icon design

Icons adopt visual symbols reminiscent of 1980s home appliances, such as the knob style from the 1985 Peony brand television and kerosene lamp symbols. Lu M H et al. indicate that seniors recognize such icons at a rate exceeding 90%; fMRI scans also reveal a 40% increase in hippocampal activity when seniors view these icons. Technically, icons must not be smaller than 15mm × 15mm, and color contrast must not fall below 4.5:1 [23]. A 2023 Tsinghua University study found that using nostalgic icon designs increased user icon recognition accuracy by 22–35%. This demonstrates that older adults tend to accept visual symbols linked to their past experiences more readily and retain them better [24].

#### 7.1.2 Functional navigation

Functional navigation categorizes entry points according to the "Morning - Noon - Evening" time periods. The design follows the "3-5-2" hierarchy principle: the main menu contains no more than 3 items, submenus no more than 5 items, and terminal actions no more than 2 steps. Additionally, corresponding lifestyle illustrations are added beside menus—such as sunrise images for the morning segment—to enhance contextual cues and improve operational intuitiveness [25].

#### 7.1.3 Feedback design

Feedback design employs simulated sounds from traditional devices, like the echo of old typewriters or the winding mechanism of mechanical alarm clocks. These familiar auditory cues evoke emotional memories among seniors, reinforcing confirmation during operations.

Frequencies should be controlled within the 500 to 3000Hz range, with durations lasting 0.5 to 1 second to prevent startling reactions among older adults. The concept of "culturally adaptive auditory feedback" proposed by Wang Yue et al.

emphasizes that auditory cues must align with users' cultural backgrounds and usage habits. Only then can feedback be more readily accepted, thereby enhancing the user experience [26].

The multimodal collaborative solution incorporates vibration feedback and icon bounce effects, with the bounce amplitude controlled within 5% to achieve synchronized auditory and tactile feedback [27].

### 7.2 Key technology implementation

When applying key technologies, designers can incorporate nostalgic elements into product interfaces or allow users to customize settings—such as setting vintage photos as interface backgrounds. These memory-triggering elements evoke emotional recollections in older adults, fostering familiarity with the product and increasing willingness to use it [28].

Additionally, scene mode switching is crucial. When the system detects a time point matching irrigation scenarios, it automatically triggers context-aware mechanisms, seamlessly transitioning to irrigation control interfaces to deliver task-driven contextual functionality. This design demonstrates precise understanding and support for seniors' daily routines and activities [29]. Alibaba Senior Research Institute proposed a "scenario-based classification" design methodology. This approach categorizes and integrates functions by time or context, thereby reducing the probability of operational errors [30]. It alleviates the cognitive burden on seniors when operating products, enabling them to use smart devices more effortlessly.

### 7.3 Pre-screening of experimental materials

To ensure comparability between nostalgic and modern icons in non-nostalgic attributes, and to eliminate potential interference from confounding factors such as familiarity, visual concreteness, and semantic clarity, this study conducted a pre-screening of materials prior to the formal experiment.

#### 7.3.1 Participants

The pre-experiment recruited 10 elderly participants aged 60–70 years, comprising 6 males and 4 females. All participants possessed normal vision or corrected vision, exhibited no cognitive impairment, and did not overlap with participants in the formal experiment.

#### 7.3.2 Measurement tools

Three five-point scales (1 = Very low/Strongly disagree, 5 = Very high/Strongly agree) were employed to quantify the non-nostalgic attributes of candidate icons:

Familiarity: 'This icon looks familiar'

Visual concreteness: 'This icon depicts a specific object'

Semantic clarity: 'One can guess its function at a glance'

### 7.3.3 Experimental materials

Eighteen candidate icons were categorised into two groups based on era characteristics: the nostalgic icon group (9 icons, designed in an 1980s style) and the modern icon group (9 icons, designed in the current mainstream flat style). Participants rated each icon across the aforementioned three dimensions.

### 7.3.4 Preliminary experimental results

Descriptive statistics and independent samples t-test results for the preliminary experimental data are presented in *Table 1*.

Note: Familiarity, visual concreteness, and semantic clarity were measured using a 5-point Likert scale (1 = very low/strongly disagree, 5 = very high/strongly agree). Each set comprised nine icons rated by ten elderly participants. Independent samples t-tests revealed significant differences between the two groups across all three dimensions ( $p < 0.01$ ).

### 7.3.5 Interpretation of results

Preliminary findings indicate that the nostalgia icon group scored significantly higher than the modern icon group across all three dimensions: familiarity, visual concreteness, and semantic clarity ( $p < 0.01$ ). This demonstrates that the nostalgia icons designed in this study not only possess nostalgic characteristics but also exhibit systematic visual differences from modern icons—being more recognisable, more concrete, and easier to comprehend functionally.

## 8 EXPERIMENTAL VALIDATION

### 8.1 Experiment one

#### 8.1.1 Experiment objective

Examine whether the associations proposed by the LMM hypotheses H1 and H2 are supported by the observed data under the conditions of this experiment.

#### 8.1.2 Experimental design

This study selected "flat icons" as the control group, as they represent the current mainstream UI design style and possess high ecological validity. Future research may further establish control groups such as "icons + text" or "pure audio" to more comprehensively evaluate the effectiveness and applicability of the L model.

Experimental Materials: Based on pre-experimental findings, six nostalgic icons scoring high-

ly in familiarity, visual concreteness, and semantic clarity were selected from nine candidates as experimental materials for the experimental group (as shown in *Figure 2*). Six functionally corresponding modern icons were concurrently chosen as experimental materials for the control group (as shown in *Figure 3*). Both sets of icons maintained consistent physical attributes, including dimensions (15mm × 15mm) and contrast ratio ( $\geq 4.5:1$ ).

It should be noted at the outset that, although this study measured the familiarity, visual concreteness, and semantic clarity of the icons in both groups through a pilot study (see Section 7.3), the results indicate significant differences between the two groups on these non-nostalgic attributes. This implies that the experimental design did not fully control for these potential confounding variables. Consequently, the performance differences observed between groups in the experimental results cannot be uniquely and definitively attributed to the "nostalgia effect" alone, but should be regarded as the combined result of the interaction between nostalgia-related attributes and other relevant attributes (such as higher concreteness and familiarity). This study is positioned as an exploratory analysis, aiming to provide preliminary evidence for subsequent, more rigorous causal tests.

Fifteen young-old adults (aged 60–71 years, mean age  $65.4 \pm 3.2$  years) were selected. This classification follows gerontology conventions dividing old age into "young-old" (65–74 years), "middle-old" (75–84 years), and "old-old" ( $\geq 85$  years). The sample comprised seven males and eight females. All participants possessed normal vision (corrected vision) and were free from colour blindness or colour deficiency. Smartphone proficiency was assessed via a self-report questionnaire (rated 1–5, where 1 indicated 'rarely used' and 5 'highly proficient'), yielding an average score of  $2.8 \pm 0.9$ , indicating beginner to intermediate proficiency. Educational backgrounds spanned primary school (4 participants), lower secondary school (6 participants), and upper secondary school (5 participants). Inclusion criteria comprised: (1) age 60–75 years; (2) basic smartphone touchscreen operation skills (e.g., ability to tap and swipe); (3) self-reported absence of severe cognitive impairment or conditions affecting manual dexterity. Informed consent was obtained from all participants.

Following design guidelines, two smart home control interface prototypes were created: Experimental group (nostalgic icon group): Six core function icons adopted 1980s home television visual styles (e.g., "Music Playback" shaped

# Age-friendly interaction design for smart homes

Table 1. Preliminary icon screening results

Variable	Retro Icon Set (n=10)	Modern Icon Set (n=10)	t-value	p-value
Familiarity	4.11 ± 0.48	2.07 ± 0.69	7.21	<0.001
Visual Concreteness	4.63 ± 0.32	3.24 ± 1.01	3.94	=0.001
Semantic clarity	4.63 ± 0.32	2.96 ± 1.17	4.12	<0.001

like an old gramophone, "Lighting Control" shaped like a kerosene lamp) as shown in *Figure 2*, sized 15mm×15mm. Control Group (Traditional Icons): Same functions using modern flat design, matching the experimental group in size and contrast (*Figure 3*).

Six typical smart home operation tasks were set: identifying music playback, video player functions, viewing today's weather forecast, accessing photo albums, activating flashlights, and making phone calls.

Each participant completed tasks on both interface sets: randomly assigned to use either the experimental or control interface first, switching after a five-minute interval between sets. Each task had a one-minute time limit, recording: first-attempt recognition accuracy (correctly clicking the target icon), task completion time (duration from interface presentation to successful operation), and number of errors (clicking the wrong icon or repeating actions).

### 8.1.3 Experimental results

To test the hypotheses of the LMM model (H1, H2), a paired samples t-test was employed to compare performance data between the experimental group (nostalgic icons) and the control group (traditional flat icons). Descriptive statistics and inferential statistics for each metric are presented in *Table 2*.

Statistical analysis results: The first-pass recognition accuracy of the nostalgic icon group was significantly higher than that of the control group ( $t(14) = 6.58, p < 0.001$ , Cohen's  $d = 1.70$ , 95% CI [1.02, 2.38]). Task completion time was significantly shorter than the control group ( $t(14)$



Figure 2. Experimental group: nostalgic icon design (image designed by the author)

$= -4.23, p < 0.001$ , Cohen's  $d = -1.09$ , 95% CI [-1.78, -0.40]). The number of incorrect operations was significantly lower than that of the control group ( $t(14) = -6.02, p < 0.001$ , Cohen's  $d = -1.55$ , 95% CI [-2.28, -0.82]). All effect sizes ( $|d| > 0.8$ ) were classified as large effects. Consequently, the experimental findings were consistent with the direction anticipated by H1 and H2, providing preliminary, correlational evidence that nostalgia-oriented icons designed using the LMM were associated with enhanced cognitive operational efficiency among elderly users under the experimental conditions.

These findings are consistent with the predictions of the LMM model, namely that the nostalgic icon group demonstrated superior behavioral performance. However, as noted in the experimental design section, since the nostalgia icon group also scored significantly higher than the modern icon group in terms of familiarity, visual concreteness, and semantic clarity (see Section 7.3 for preliminary experimental results), the observed performance differences may be partially or entirely attributable to these confounding variables rather than a purely "nostalgic" psychological effect. For example, higher visual concreteness itself may reduce recognition difficulty. Therefore, the current data provide preliminary, indicative support for the LMM model's argument that "nostalgic symbols are associated with cognitive operational efficiency," but cannot yet confirm a causal relationship. Future research must employ experimental materials that are strictly matched on non-nostalgic dimensions to isolate the unique contribution of the nostalgia effect.

## 8.2 Experiment two

Experiment Two aimed to directly measure memory activation (nostalgia) and cognitive load (NASA-TLX) elicited by nostalgic icons, thereby testing the core pathway in the LMM model: 'nostalgic symbols → memory activation → reduced cognitive load'.

### 8.2.1 Participants

An additional 10 elderly participants meeting screening criteria were recruited, aged 60–70 years, comprising 6 males and 4 females. All participants possessed normal vision or corrected vision, exhibited no cognitive impairment, and were non-overlapping with participants from the pre-experiment and Experiment One.

### 8.2.2 Measurement instruments

Nostalgia Rating: Employed a 5-point scale (1=Strongly Disagree, 5=Strongly Agree) adapted from the Southampton Nostalgia Scale, comprising three items: 'Recalling past experiences

# Age-friendly interaction design for smart homes

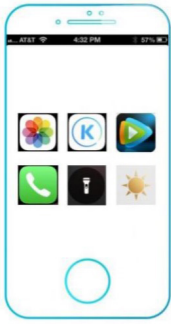


Figure 3. Control group: traditional flat icon design (image designed by the author)

or scenes,' 'Resembling objects seen in youth,' and 'Recalling fragments of past life.' The mean score across these three items served as the total nostalgia score, with higher scores indicating stronger memory activation.

**Cognitive Load:** The NASA-TLX simplified version (5-point scale) was employed, comprising six dimensions: mental demand, physical demand, time pressure, effort, frustration, and self-expression. The "Self-Perceived Performance" dimension is reverse-scored (higher raw scores indicate greater satisfaction; higher converted scores indicate greater cognitive load) to align with the direction of other dimensions. The average of the six dimensions serves as the total cognitive load score, with higher scores indicating greater subjective cognitive load.

### 8.2.3 Experimental results

#### (1) Nostalgia rating outcomes

Descriptive statistics and independent samples t-test results for nostalgia ratings across both groups are presented in Table 3.

Note: Nostalgia scores represent the average of three items (5-point scale, 1=strongly disagree, 5=strongly agree), with higher scores indicating stronger memory activation. Independent samples t-tests revealed that the nostalgia icon group scored significantly higher than the modern icon group on all items and the total score ( $p < 0.001$ ).

The results indicate that the nostalgic icon group scored significantly higher than the modern icon group on both the total nostalgia score

and all individual items. This finding is consistent with the direction predicted by Hypothesis H1 of the LMM model, suggesting that nostalgic icons are associated with a stronger experience of memory activation.

#### (2) NASA-TLX cognitive load results

Descriptive statistics and independent samples t-test results for each dimension and total score of the NASA-TLX across both groups are presented in Table 4.

Note: The NASA-TLX dimensions employ a 5-point scale (1 = very low, 5 = very high). The "Self-Performance" dimension has been reverse-scored to align with the other dimensions (i.e., higher raw scores indicate greater satisfaction; higher converted scores indicate greater workload). The total score is the average of the six dimensions. Independent samples t-tests revealed that the nostalgia icon group scored significantly lower than the modern icon group across all dimensions—cognitive demand, physical demand, time pressure, effort, frustration, and total score ( $p < 0.05$ ).

The results showed that the nostalgic icon group scored significantly lower on the NASA-TLX total score than the modern icon group. This finding is consistent with the direction predicted by Hypothesis H2 of the LMM model, indicating that enhanced memory activation is associated with reduced subjective cognitive load. Combining the results of Experiment 1 and Experiment 2, we observed a consistent pattern of association between "the use of nostalgic icons" and "better behavioral performance and lower cognitive load." Experiment 2 directly measured memory activation (nostalgia), providing preliminary procedural evidence for the core pathways of the LMM model. However, because the experimental materials were not matched on confounding variables such as familiarity and concreteness, we cannot assert that the observed differences in memory activation and cognitive load were caused solely by "nostalgia." These confounding variables may also influence scores of nostalgia and cognitive load. Therefore, the current evidence should be regarded as indicative support for the mechanisms of the LMM model rather than definitive validation.

Table 2. Cognitive efficiency comparison between nostalgic and traditional icons

Indicator	Experimental Group (Mean ± SD)	Control Group (Mean ± SD)	Paired t-test p-value
First-pass recognition accuracy (%)	95.55±7.64	61.11±21.52	<0.001
Task completion time (seconds)	56.20±13.08	68.67±15.79	<0.001
Number of incorrect operations	0.27±0.46	2.33±1.29	<0.001

# Age-friendly interaction design for smart homes

Table 3. Comparison of nostalgia scores between the two groups

Group	Overall Nostalgia Score	Recalling past experiences or scenes	Resembling objects encountered in youth	Recalling fragments of past life
Nostalgic icon set	4.57 ± 0.47	5.00 ± 0.00	4.70 ± 0.48	4.00 ± 1.15
Modern icon set	1.50 ± 0.42	1.50 ± 0.85	1.70 ± 0.82	1.30 ± 0.67
t-value	15.34	11.18	9.87	6.45
p-value	<0.001	<0.001	<0.001	<0.001

### 8.3 Experimental limitations

This study presents the following limitations, which require refinement in future work:

**Sample and ecological validity constraints:** The sample size for Experiment 1 (behavioural performance) was 15 participants, while Experiment 2 (core mechanisms) involved 10 participants, both drawn from the same urban community. This limits the generalisability of findings. The experimental tasks comprised simplified single-page click operations, failing to encompass the complex multi-level navigation, status feedback, and concurrent task scenarios found in real smart home systems, thus necessitating enhancement of ecological validity.

**Phase-specific participant differences:** The pre-experiment (n=10), Experiment One (n=15), and Experiment Two (n=10) each recruited independent samples of older adults. Although no cross-phase comparison was intended, possible differences in age distribution, educational background, cognitive status, or prior technology experience among these participant groups may have influenced the overall pattern of results. Future research should use a single cohort of participants across all phases to eliminate this potential confound.

**Fundamental Limitations of Confounder Control:** This is the most critical limitation of this study. As demonstrated in the pilot study in Section 7.3, the nostalgic and modern icons used in this study exhibited systematic differences in familiarity, visual concreteness, and semantic clarity,

and thus failed to be matched. This directly prevents us from uniquely attributing the observed between-group differences (whether in behavioural performance or subjective experience) to the psychological construct of “nostalgia.” This limitation severely undermines the strength of causal inference regarding the study’s central argument, necessitating that all findings be interpreted as exploratory, correlational, and preliminary evidence. Although Experiment 2 directly measured feelings of nostalgia, the measurement itself may also have been influenced by characteristics such as the concreteness of the icons. Future research must overcome this limitation through rigorous material selection (e.g., selecting nostalgic/non-nostalgic icons matched for familiarity and concreteness, or adopting an experimental separation paradigm).

**Mechanism measurement limitations:** Experiment 2 directly assessed memory activation and cognitive load via subjective scales (nostalgia ratings, NASA-TLX), providing direct evidence for the core pathways of the LMM model. However, subjective reporting may be influenced by participants’ introspective abilities and social desirability bias, and the sample size was small (n=10). Future research should incorporate objective physiological indicators such as eye-tracking and electroencephalography (EEG), combined with multimodal data, to rigorously test the causal chain: ‘symbol presentation → memory activation → reduced cognitive load’.

**Longitudinal and learning effect limitations:** The intra-subject design employed, despite ran-

Table 4. Comparison of NASA-TLX scores between two groups

Dimension	Retro Icon Set	Modern Icon Set	t-value	p-value
Mental demands	2.40 ± 1.35	3.90 ± 1.10	-2.71	0.014
Physical demands	2.00 ± 1.33	3.60 ± 0.97	-3.04	0.007
Time pressure	2.30 ± 0.82	3.70 ± 0.48	-4.67	<0.001
Effort level	2.40 ± 1.35	4.30 ± 0.82	-3.80	0.001
Frustration	2.10 ± 1.20	4.20 ± 0.79	-4.61	<0.001
Self-performance (inverse)	2.60 ± 1.84	2.10 ± 0.74	0.80	0.434
NASA-TLX total score	2.30 ± 0.80	3.63 ± 0.51	-4.42	<0.001

domised task order and inter-trial intervals, may still introduce learning or order effects. The absence of longitudinal tracking precludes assessment of the nostalgia icon effect's persistence and potential habituation or attenuation following prolonged exposure. Future longitudinal studies spanning 4–8 weeks could examine the stability and user acceptance of nostalgic design in extended usage.

Despite these limitations, this study observed the behavioural performance enhancement of nostalgic icons through Experiment 1 and directly measured the mediating role of memory activation and cognitive load reduction in Experiment 2. The two experiments corroborate each other, collectively providing preliminary correlational evidence consistent with the theoretical pathway proposed by the LMM model: 'nostalgic symbols → memory activation → reduced cognitive load'. Nostalgic icons may form 'cognitive shortcuts' by activating older adults' episodic memory and emotional resonance, thereby reducing symbol decoding time and working memory load. This aligns with fMRI findings showing enhanced hippocampal activation in response to nostalgic stimuli [31], providing preliminary empirical support for the LMM model.

## DISCUSSION AND FUTURE DIRECTIONS

As an exploratory study, this research is the first to integrate the “nostalgic symbols—memory recall—cognitive load reduction” mechanism

into a testable LMM model. Through behavioral experiments and subjective reports, it provides preliminary, indicative empirical support for the model's core hypotheses. The results suggest that using nostalgic symbols familiar to older adults in interface design may help improve their operational efficiency and reduce subjective cognitive load. However, due to a fundamental limitation—namely, the lack of matching across key dimensions such as familiarity and concreteness in the experimental materials—the findings of this study must be regarded as preliminary evidence of an association rather than direct validation of the causal role of the “nostalgia effect.”

Future research should first address the core limitations of this study by designing pairs of nostalgic and modern icons that are strictly matched in non-nostalgic attributes such as familiarity, visual concreteness, and semantic clarity, or by adopting more sophisticated experimental paradigms (such as priming paradigms) to isolate the unique contribution of “nostalgia” in a controlled manner. Building on this foundation, future research should expand the sample size to include participants from diverse geographic regions and educational backgrounds, incorporate multimodal physiological measures such as eye-tracking and EEG, conduct longitudinal tracking studies, and transfer the model to more complex real-world scenarios—such as healthcare and transportation—to test its long-term effects and generalizability.

## References

- [1] Ministry of Civil Affairs of the People's Republic of China & National Bureau of Statistics. (2024, October 11). 2023 national development bulletin on aging affairs [Report].
- [2] Liu, S. (2013). Effects of early experiences with interaction style on usability and acceptance of new technologies by older adults: A generation-oriented approach (Doctoral dissertation). North Carolina State University.
- [3] Yang, W., & Wang, Q. (2024). Research on age-friendly packaging design based on user needs. *China Packaging*, 44(5), 125–127.
- [4] Liu, Y., & Chen, J. (2024). Research on user interface interaction experience design for age-friendly apps. *Shanghai Packaging*, (5), 165–167. <https://doi.org/10.19446/j.cnki.1005-9423.2024.05.053>
- [5] Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, 103(3), 403–428.
- [6] Tisserand, D. J. (2003). Structural and functional changes underlying cognitive aging: Evidence from neuroimaging studies (Doctoral dissertation). Maastricht University.
- [7] Mas-Tous, C. (2008). Memory improvement in the elderly: Variables to consider. *Papeles del Psicólogo*, 29(2), 213–221.
- [8] Nielsen, S., & Wilms, I. L. (2015). Cognitive aging on latent constructs for visual processing capacity: A novel structural equation modeling framework with causal assumptions based on a theory of visual attention. *Frontiers in Psychology*, 5, 1596. <https://doi.org/10.3389/fpsyg.2014.01596>
- [9] Zhu, X. (2016). Research on spatial mismatch in public rental housing (Master's thesis). Huazhong University of Science and Technology.
- [10] Zhu, J. (2012). Research on supply and demand of community health services for the elderly (Master's thesis). Huazhong University of Science and Technology.
- [11] Li, J. (2018). Survey research on supply and demand of home-based elderly care services in Shijiazhuang City (Master's thesis). Hebei Normal University.
- [12] Yan, B., Sun, W., & Wang, Y. (2011). Mismatch and countermeasures in supply and demand of rural financial services. *Knowledge Economy*, (3), 78–79. <https://doi.org/10.15880/j.cnki.zsjj.2011.03.130>
- [13] Zhang, Y. (2013). Research on supply and demand of rural commercial pension insurance (Master's thesis). Fujian Agriculture and Forestry University.
- [14] Yang, Y. (2016). Supply and demand of ceramics in the Song Dynasty (Master's thesis). Yunnan University.

# Age-friendly interaction design for smart homes

- [15] Chen, X. (2023). Cross-cultural metaphor misunderstanding in elderly-friendly interfaces. *International Journal of Human-Computer Interaction*, 39(2), 312–328.
- [16] World Health Organization. (2021). *Guidelines on sensory feedback for elderly digital interface design*. WHO Press.
- [17] Liu, C., Zhang, Q., & He, Y. (2023). Environmental noise impairs tactile feedback efficacy in elderly users. *IEEE Transactions on Human-Machine Systems*, 53(1), 89–97.
- [18] Apple Aging Lab. (2022). *Accessibility design for older adults: Touch interaction optimization [Report]*. Apple Inc.
- [19] Alibaba Health. (2023). *Location-based medication navigation system for elderly users [Technical white paper]*.
- [20] Peking University Laboratory of Gerontological Psychology. (2023). *Emotional design for elderly health applications [Research report]*.
- [21] Tencent AI Lab. (2022). *Ethical considerations in elderly memory cue generation [Report]*. Tencent Research.
- [22] Pitts, B. L. (2022). Semantic knowledge attenuates age-related differences in event segmentation and episodic memory. *Memory & Cognition*, 50(3), 1–28. <https://doi.org/10.3758/s13421-022-01234-5>
- [23] Lu, M. H., Lin, W., & Yueh, H. P. (2017). Development and evaluation of a cognitive training game for older people: A design-based approach. *Frontiers in Psychology*, 8, 1837. <https://doi.org/10.3389/fpsyg.2017.01837>
- [24] Xin, X. (2015). Interaction design: From physical logic to behavioral logic. *Decoration*, (1), 58–62. <https://doi.org/10.16272/j.cnki.cn11-1392/j.2015.01.012>
- [25] Zao, J. K. (2008). Activity-oriented design of Health Pal: A smart phone for elders' healthcare support. *EURASIP Journal on Wireless Communications and Networking*, 2008, Article 582194. <https://doi.org/10.1155/2008/582194>
- [26] Wang, Y. (2018). *Research on interface interaction design based on cognitive characteristics of the elderly (Master's thesis)*. Nanjing University of Science and Technology.
- [27] Fang, M., Yang, W., Li, H., & Pan, Y. (2023). Enhancing user experience through optimization design method for elderly medication reminder mobile applications: A QFD-based research approach. *Electronics*, 12(13), 2860. <https://doi.org/10.3390/electronics12132860>
- [28] Wang, Y., Huang, L., & Dong, C. (2023). Research on age-friendly product design based on the theory of care. *Industrial Engineering Design*, 5(4), 73–82. <https://doi.org/10.19798/j.cnki.2096-6946.2023.04.010>
- [29] Zhou, M., & Li, Y. (2017). Research on product interaction aging-friendly design for elderly care services with Chinese characteristics. *Art Hundred Schools*, 33(1), 233–234.
- [30] Li, L. X. (2025). Learning from elders: Making an LLM-powered chatbot for retirement communities more accessible through user-centered design. In *Proceedings of the 88th Annual Meeting of the Association for Information Science & Technology* (pp. 100–115). Association for Information Science and Technology.
- [31] Yang, Z. (2022). Patterns of brain activity associated with nostalgia: A social-cognitive neuroscience perspective. *Social Cognitive and Affective Neuroscience*, 17(4), 185–198. <https://doi.org/10.1093/scan/nsac015>