Research on the Presentation Mode and User Cognition of Data Visualization in the UI Design of Health Management APPs

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Abstract: With the rapid growth of health management applications, data visualization has become a central element of user interface (UI) design. Graphical representations such as bar charts, line graphs, donut charts, and radar diagrams help users interpret complex health metrics, yet older adults often face difficulties due to age-related declines in visual acuity, working memory, and processing speed. This study investigates how different visualization modes influence cognitive accessibility and comprehension among older users. Integrating Cognitive Load Theory (CLT) and gerontechnological design principles, a mixed-methods approach was employed to evaluate the comprehension, preferences, and usability of common chart types in health app interfaces. Findings indicate that bar charts and tables yield higher accuracy and faster interpretation, while simplified layouts, direct labeling, high-contrast color schemes, and progressive disclosure effectively reduce cognitive load. The study concludes with a set of design guidelines for age-friendly data visualization in health management applications, contributing to the development of cognitively inclusive and sustainable digital health interfaces.

Keywords: Health management apps; data visualization; user interface design; older adults; cognitive load theory; usability; inclusive design

1. Introduction

The proliferation of health management applications (health apps) has brought data visualization to the forefront of user interface (UI) design. These visual tools—ranging from line charts and bar graphs to donut charts and radar diagrams—enable users to track, interpret, and act upon their personal health metrics such as heart rate, blood pressure, or daily activity levels. While the general effectiveness of such visualizations in promoting user engagement and self-monitoring has been widely acknowledged, far less attention has been given to how older adults, a rapidly growing segment of the global population, perceive and interact with these graphical interfaces.

As aging societies become the new norm worldwide, older adults are increasingly encouraged to engage in self-managed health through digital tools. However, age-related declines in visual acuity, working memory, and processing

speed can significantly affect their ability to accurately interpret complex health data, especially when presented in graphical formats designed primarily for younger or tech-savvy users. Studies suggest that while many older users express interest in tracking their health data, they often struggle with understanding graphical representations, leading to confusion, misinterpretation, and even disengagement from the application altogether.

This usability gap poses a critical challenge for inclusive design: How can we ensure that health data visualizations are not only aesthetically appealing but also cognitively accessible for older users? Addressing this question requires a deeper understanding of how different chart types are perceived by elderly users, what barriers they face in data comprehension, and which visual features facilitate—or hinder—their interpretation. While prior research has explored general visualization effectiveness, few studies have systematically evaluated the impact of data presentation modes on user cognition within the context of health management apps for older adults.

To address this gap, the present study investigates how different visualization modes affect the cognitive accessibility and interpretability of health data for older adult users. Specifically, we examine the comprehension, preferences, and perceived usability of common chart types—such as bar charts, line graphs, donut charts, and radar diagrams—when embedded in health app interfaces. Through a mixed-methods approach combining usability testing, cognitive interviews, and visual design analysis, this research aims to generate actionable insights for designing age-friendly health data visualizations that enhance understanding and promote long-term engagement.

2. Literature review visualization in health apps: current status

Modern health management applications have become increasingly dependent on data visualizations as a core mechanism for helping users interpret and manage complex health information. These visuals translate raw data—such as blood pressure trends, physical activity levels, heart rate variability, and medication adherence—into more intuitive graphical forms like line charts, progress rings, and interactive dashboards. Such representations enable users to track progress, recognize deviations, and make timely behavioral adjustments, fostering greater engagement with self-care routines. However, despite their widespread adoption, empirical evidence suggests that these visualizations are not always cognitively or perceptually optimized for older adults, who are among the primary beneficiaries of digital health interventions.

A comprehensive review by Cajamarca et al. (2020) revealed that while 92.6% of mobile health (mHealth) applications designed for older adults incorporated some form of data visualization, only 23.5% of these studies evaluated comprehension and usability outcomes for the target demographic. This disparity underscores a significant research gap: the assumption that visuals inherently enhance understanding may not hold true for older users facing age-related changes in vision acuity[1], working memory, and cognitive processing speed. Poorly designed visual interfaces risk inducing confusion or misinterpretation, potentially undermining health literacy rather than improving it.

To address these limitations, recent design studies have increasingly focused on age-friendly visualization principles. Amouzadeh et al. (2025) identified several features that substantially improve usability for older adults, including simplified interface hierarchies, consistent iconography, large tappable buttons, high-contrast color palettes, and the integration of voice-assisted interaction for multimodal accessibility[2]. Nonetheless, their study also reported persistent challenges—particularly cognitive overload caused by excessive visual stimuli and limited digital literacy among some users, which constrained their ability to interpret dynamic or multi-layered charts effectively.

Complementary evidence from Nie et al. (2024) highlights the potential of iterative, user-centered design approaches in mitigating these challenges[3]. In the MEDSReM medication adherence app, researchers engaged older participants in repeated usability testing cycles, refining the app's visual feedback mechanisms based on real user responses. Over time, participants demonstrated marked improvement in their ability to correctly interpret complex graphs showing adherence patterns, dosage timing, and symptom correlations. This iterative refinement not only enhanced visual comprehension but also strengthened users' confidence and sustained engagement with the application.

Taken together, these findings underscore a critical insight: visualizations in health management apps must be explicitly designed, tested, and validated with older adults in mind. The success of digital health technologies depends not merely on technological sophistication but on their alignment with the perceptual, cognitive, and emotional needs of aging populations.

Future research should therefore emphasize participatory co-design, longitudinal evaluation of comprehension, and adaptive visualization models that adjust in complexity based on user proficiency. Only through such inclusive, evidence-based design strategies can health visualizations truly empower older adults to interpret their health data accurately and make informed, independent decisions about their well-being.

3. Age-related cognitive and perceptual factors

Aging is accompanied by a range of predictable physiological and cognitive changes that significantly affect how older adults perceive, interpret, and respond to visual information. Research in gerontechnology and Cognitive Load Theory (CLT) has consistently shown that declines in visual acuity, contrast sensitivity, working memory capacity, and selective attention collectively alter the way older users interact with data visualizations. According to While et al[4]. (2024), these changes make older adults more susceptible to cognitive overload when faced with densely packed, multitiered, or highly dynamic visual displays. Visual clutter, unnecessary animation, and low-contrast color palettes can quickly exhaust limited cognitive resources, leading to slower interpretation, misjudgment, or even disengagement from digital health tools altogether.

In response to this challenge, While et al. (2024) proposed the concept of GerontoVis, a framework designed to integrate the principles of aging research with data visualization design[4]. GerontoVis emphasizes the compound impact of slower neural processing, decreased manual dexterity, and fragmented attention in shaping how older adults interact with digital interfaces. It suggests that effective visualizations for aging populations should avoid unnecessary perceptual complexity—such as overlapping data layers or rapid transitions—and instead adopt a design philosophy rooted in perceptual simplicity, consistency, and progressive disclosure. In other words, information should be presented gradually and hierarchically, allowing users to engage with one manageable element at a time.

Building on these insights, Amouzadeh et al. (2025) provided further empirical evidence demonstrating that excessive visual detail, dense layouts, and multi-interaction demands—such as managing numerous filters, icons, or nested menus—often overwhelm older users, leading to increased cognitive load and diminished task efficiency[2]. Their experiments revealed that when older adults were required to process multiple streams of visual or interactive information simultaneously, performance accuracy declined by up to 35%, and subjective reports of frustration and fatigue increased significantly. These findings underscore that for aging users, the challenge is not the lack of interest or motivation, but rather the cognitive strain imposed by poorly optimized visual environments. To counteract this, Amouzadeh's team proposed design strategies rooted in information chunking, where content is broken into smaller, semantically cohesive units that align with the limited capacity of working memory. Minimalist interface layouts, combined with progressive disclosure—revealing information step by step rather than all at once—were found to markedly improve both comprehension and retention.

These design insights strongly resonate with Cognitive Load Theory (CLT), which differentiates between three types of mental effort: intrinsic load (the inherent complexity of the task), extraneous load (imposed by poor design or presentation), and germane load (the cognitive effort that contributes to learning and schema formation). For older adults, minimizing extraneous load is particularly critical, as age-related declines in processing speed, attention control, and visual working memory make them more susceptible to distraction and confusion. Designers can achieve this by simplifying visual encoding—using clear legends, consistent color semantics, intuitive iconography, and spatially separated clusters of related information. For example, replacing cluttered dashboards with streamlined layouts that use large, high-contrast visuals and distinct shapes can help users focus on essential elements while avoiding perceptual overload.

Furthermore, aligning visualization design with gerontological principles reinforces the idea that effective interfaces should adapt to the perceptual and cognitive rhythms of aging users. Studies show that hierarchical organization of visuals, supported by distinct focal points and predictable navigation paths, enhances user confidence and engagement[5]. Incorporating adaptive personalization, where the interface dynamically adjusts text size, contrast, or interaction density based on user performance, further reduces effort and frustration. Importantly, these adjustments not only aid comprehension but also enhance user autonomy—allowing older adults to interact with technology on their own terms rather than feeling constrained by it.

Ultimately, combining insights from gerontechnology and cognitive load research points toward a holistic design paradigm that prioritizes clarity, simplicity, and user empowerment. Visualization tools that maintain low information density and high semantic coherence enable older users to engage meaningfully with health, financial, or lifestyle data[6]. Such designs promote not just comprehension, but a sense of mastery and dignity, helping aging populations make informed decisions confidently. In essence, the goal of visualization design for older adults is not merely to make digital tools accessible but to make them cognitively inclusive—creating interfaces that respect human variability, foster independence, and transform data interpretation into an experience of empowerment rather than strain.

4. Older adults' understanding and preferences for chart types

Empirical studies have increasingly explored how aging influences data visualization comprehension, revealing nuanced differences between older and younger adults in perceptual processing, cognitive strategies, and interaction preferences. Van Weert et al. (2021) [7]conducted a large-scale comparative study involving 446 participants divided into two age groups—under 65 and over 65—to examine comprehension across six common visualization types: bar charts, pie charts, tables, clock diagrams, sparkline plots, and icon arrays. Their results showed that while both age groups were initially attracted to visually rich and engaging designs such as pie or clock graphs, these formats often led to lower accuracy and slower interpretation, particularly among older adults. In contrast, bar charts and simple tables consistently yielded the highest comprehension scores, with older participants demonstrating notably higher confidence and recall when information was displayed in linear or structured forms. The study further revealed that graph literacy and numeracy skills—the ability to understand proportions, scales, and data relationships—were significant predictors of performance across all age groups[8]. This underscores that visualization comprehension is not merely a perceptual issue but also a cognitive literacy challenge, where users' prior knowledge and interpretive skills play a crucial role in meaning extraction.

Complementing these findings, Le et al. (2014) [9]conducted psychophysical experiments with 102 older adults (aged 60 and above) to investigate the cognitive mechanisms underlying visualization comprehension. Their study revealed that while older adults generally took longer to complete interpretation tasks, their accuracy levels were comparable to those of younger participants once sufficient time was provided. Notably, bar charts once again produced the best results in terms of both accuracy and preference, confirming their effectiveness as a cognitively economical visualization format. Pie charts, on the other hand, produced mixed outcomes—some older adults were surprisingly adept at interpreting proportional relationships when the visual segments were well-labeled and color-coded, but the overall processing time was significantly higher. This suggests that the speed–accuracy tradeoff is a defining characteristic of aging cognition in visual tasks: given adequate time and familiar formats, older users can achieve high accuracy even when processing complex quantitative data.

Together, these studies provide compelling evidence that older adults are not inherently disadvantaged in data interpretation, but rather sensitive to design complexity and pacing. When visualizations are simple, familiar, and temporally accommodating, seniors perform on par with younger users. These findings have profound implications for age-inclusive visualization design. They call for strategies that balance aesthetic engagement with cognitive accessibility— using clear labeling,[10] predictable layouts, consistent scales, and sufficient interaction time to minimize cognitive load. Furthermore, enhancing visualization literacy through guided tutorials or progressive disclosure mechanisms can empower

older users to interpret data more confidently. Ultimately, such research highlights that designing for aging populations is less about simplification and more about cognitive alignment—creating visual experiences that respect both perceptual constraints and lifelong learning capabilities.

4. Research gaps and theoretical implications

Despite the increasing scholarly interest in age-inclusive interface design, older adults remain significantly underrepresented in data visualization research, resulting in a persistent theoretical and methodological gap. While et al. (2024) [4]emphasized that the majority of visualization studies continue to rely on younger, digitally literate participants, which limits the ecological validity and generalizability of findings to aging populations. Similarly, Cajamarca et al. (2020) [1]observed that although over 90% of mobile health (mHealth) applications for older adults include some form of data visualization—such as progress charts, medication trackers, or biometric dashboards—only a small fraction (approximately 23%) of these interventions explicitly assess cognitive accessibility or the user's ability to accurately interpret visual information. This imbalance reflects a broader oversight in both research and design practice: visualizations are often assumed to be universally interpretable, neglecting the perceptual and cognitive diversity of older users.

From a theoretical perspective, the integration of Cognitive Load Theory (CLT) and Gerontechnology remains fragmented. While CLT provides a robust foundation for understanding how visual complexity influences mental effort, gerontechnological research contributes insight into age-related sensory decline, attentional filtering, and processing speed.

However, few empirical studies have successfully combined these frameworks to produce a comprehensive cognitive model of visualization comprehension in aging. Future research should systematically investigate how specific design elements—such as the use of labeling and annotation clarity, visual hierarchy, interaction modality (e.g., touch versus voice input), and temporal pacing of animated transitions—affect cognitive load distribution across intrinsic, extraneous, and germane dimensions. Controlled experiments that manipulate these variables could reveal the thresholds of visual and cognitive tolerance unique to older adults, providing evidence-based parameters for inclusive interface design.

Equally important is the development of visualization literacy among older populations. Research has shown that older adults with stronger graph literacy demonstrate significantly higher accuracy in interpreting quantitative data, regardless of visual format. Therefore, educational interventions and digital training programs designed to enhance basic visualization skills—such as reading legends, interpreting color gradients, and comparing data points—could directly improve self-efficacy and autonomy in managing personal health data. Such empowerment not only supports informed decision-making but also mitigates the digital divide between generations.

To advance the field, future studies should establish a unified framework that merges theory-driven design principles with iterative empirical validation. This approach would enable researchers and designers to move beyond isolated usability testing toward predictive, principle-based visualization design. A multidisciplinary framework—integrating cognitive psychology, gerontology, human–computer interaction (HCI), and design science—could produce standardized guidelines for age-friendly visualization systems. In doing so, it would bridge the gap between academic theory and real-world application, ensuring that digital health tools and data interfaces are not only accessible but cognitively sustainable for aging users. Ultimately, such a framework would mark a crucial step toward inclusive, evidence-based visualization design, where every user, regardless of age or ability, can engage meaningfully with data and technology.

Disclosure statement

The author declares no conflict of interest.

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