Impact of Navigation Structure and Cognitive Load on Digital Library User Experience among Elderly Readers: An Empirical Study of the National Digital Library (Postprint)

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Abstract

[Purpose/Significance] Through analyzing the impact of digital library navigation structure and cognitive load on elderly readers' affective experience and usability in digital reading, this study proposes design optimization recommendations.

[Method/Process] Targeting commonly used functions of the National Digital Library, a rigorous controlled experimental method was employed. Elderly readers were invited to complete tasks sequentially across different navigation structures under both high and low cognitive load conditions, to separately examine the effects of navigation structure and cognitive load on elderly readers' reading experience.

[Results/Conclusions] Digital library navigation structure has significant effects on elderly readers'affective experience, perceived usability, and task performance. Furthermore, there is an interaction effect between cognitive load and navigation structure. When these two conditions interact, they exert significant influence on readers' affective experience and reading performance in digital libraries.

Full Text

Preamble

An Empirical Study on the Effects of Navigation Structure and Cognitive Load on Digital Library User Experience Among Elderly Readers: A Case Study of the National Digital Library of China

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Abstract

[**Purpose/Significance**] This study analyzes the impact of digital library navigation structure and cognitive load on the emotional experience and perceived usability of elderly readers during digital reading, proposing design optimization recommendations. [**Method/Process**] Focusing on commonly used functions of the National Digital Library of China, a rigorous controlled experimental method was employed. Elderly readers were invited to complete tasks across different navigation structures under both high and low cognitive load conditions to validate the effects of navigation structure and cognitive load on reading experience. [**Result/Conclusion**] The navigation structure of digital libraries has significant effects on elderly readers' emotional experience, perceived usability, and task performance. Furthermore, cognitive load and navigation structure exhibit interactive effects; when both factors operate simultaneously, they exert significant influence on readers' emotional experience and digital library reading performance.

Keywords: digital library; user experience; emotional experience; cognitive load; navigation structure

With improvements in domestic network speeds, exponential growth in information resources, and enhanced public awareness of information copyright protection, the bottleneck hindering digital library development is no longer technical issues but rather user experience and reading preferences. How to attract readers to use digital libraries, increase user stickiness, and improve the utilization of information resources has become an urgent problem for libraries to address. User experience refers to all reactions and outcomes that people have when using or expecting to use a product, system, or service [?]. Most current research on digital library user experience focuses on theoretical model construction [?], leveraging new technologies such as cloud computing to enhance user experience [?], comparative analyses of interactive experiences [?], user profiling [?], and usability evaluation [?]. However, in the process of user experience research, scholars have over-relied on system usability measurement metrics proposed by J. Nielsen et al., such as system ease of use, response speed, and interface friendliness [?], which have certain limitations in exploring the emotional experience that digital libraries bring to readers. Therefore, the factors affecting changes in readers' emotional experience and their mechanisms of action require further investigation.

This study explores how different navigation structures of digital libraries affect readers' emotional experience under varying cognitive load conditions. Using a rigorous controlled experimental method and the classic Positive and Negative Affect Schedule (PANAS), we measured changes in readers' emotions before and after using digital libraries while also assessing task performance and system usability, aiming to comprehensively understand readers' digital library user experience. The research on digital library emotional experience in this paper expands upon existing studies by quantifying readers' emotions—a psychological activity that is difficult to observe—through repeated measurement methods. This will help us more completely analyze the changing process of user experience and provide theoretical foundations for the design, development, and iterative upgrading of digital libraries.

Literature Review

The components of user experience are complex. M. Hassenzahl believes that user experience emerges from the interaction between users' internal states (needs, motivations, expectations, mood, etc.) and product systems in specific environments [?]. He operationally divides user experience into pragmatic experience and hedonic experience. Pragmatic experience generally refers to system usability, functional usefulness, and ease of use, while hedonic experience includes ten types of psychological needs such as user emotion, sense of value, and self-enhancement [?]. Related research has found that the goal of usability experience is to ensure users can successfully use a product, whereas good hedonic experience not only retains users but also predicts their future usage behavior [?]. Therefore, research on the hedonic experience of digital libraries is crucial for improving knowledge service efficiency.

In recent years, various physical libraries have been actively developing digital libraries, exploring new forms of knowledge services to enhance efficiency. Research on digital library user experience can be broadly divided into two categories. First, theoretical construction of digital library user experience: for example, Xu Fang et al. divided digital library user interaction into three types—user-system interaction, user-user interaction, and user-environment interaction—constructing a digital library user interaction model based on user experience [?]. Zhang Ning et al. proposed a user experience service model for the National Library of China across four dimensions: service content, service method, service target, and technical means [?]. Deng Shengli et al. built an adaptive information service model based on user experience in interactive information services [?]. Second, user experience evaluation of digital libraries: for instance, Xu Fang et al. used experimental and comparative research methods to compare user interaction experiences across CNKI, VIP, and Wanfang digital libraries, analyzing their respective strengths and weaknesses to provide recommendations for improving user experience [?]. Additionally, they further analyzed the impact of individual differences on digital library user experience evaluation, finding that educational background, gender, and other factors significantly influence user experience evaluation [?]. Zheng Fangqi et al. conducted a comparative analysis of human-computer interaction interfaces of two digital reading applications, summarizing several interface characteristics and development trends such as personalization and socialization [?]. K.C. Wu et al. used structural equation modeling to study children' s information search experience in digital libraries, finding that game-like icons and interface layout significantly help children' s information search and proposed design recommendations for children' s digital libraries [?].

Emotional experience, as an important component of user experience, not only directly affects information behavior decision-making and information search performance but also influences users' loyalty and satisfaction with information service platforms. Information search motivation is affected by emotional factors. Liu Luchuan et al. identified 16 emotions most frequently experienced by users during information search and found that positive emotions can significantly enhance user satisfaction [?]. Zhao Yang et al. discovered that user satisfaction positively affects users' continuous usage intention [?]. Cha Xianjin et al. found that information quality and source credibility both positively influence users' cognitive and emotional responses, which in turn positively affect users' academic information search behavior [?]. Research has shown that time pressure affects confidence and self-identity in successfully completing search tasks during information retrieval [?], and time pressure is an important means of controlling cognitive load. Liu Jia et al. measured users' cognitive load by calculating information search task completion time, constructing a cognitive load structural model for the information retrieval process and proposing a basic framework for cognitive load evaluation [?]. Using cognitive load as an independent variable to study its impact on emotional experience is significant for improving information retrieval performance.

In summary, although these studies provide theoretical and practical guidance for digital library development, they have the following limitations: (1) They only selected pragmatic experience evaluation indicators for user experience, with emotional experience research focusing mainly on factor analysis rather than empirical studies on how readers' emotional experiences change during reading. (2) Readers often experience certain cognitive loads when using digital libraries, which vary with usage contexts. For example, novice and expert users may experience very different cognitive loads when completing the same task, resulting in user experience differences. This is an unavoidable important factor in reality. While previous research has established a basic framework for cognitive load evaluation in information search, how cognitive load affects readers' emotional experience requires further investigation. (3) Most research subjects have been students, with few focusing on children, and even fewer on elderly populations. Therefore, this study addresses these gaps by targeting elderly readers of the National Digital Library of China, investigating different navigation structures and cognitive loads to comprehensively explore how these two factors affect users' emotional experience and perceived usability.

Theoretical Background and Research Hypotheses

Based on cognitive load theory, this study uses time pressure to regulate cognitive load and examines the existing two navigation forms of the National Digital Library of China. Using a controlled experimental method, we explore their respective effects on task performance, emotional experience, and usability.

3.1 Cognitive Load

Cognitive load refers to the total amount of cognitive resources required for information processing during task completion [?]. Related research shows that changes in cognitive load lead to changes in task performance, with a “ ” shaped relationship between cognitive load growth and task performance—both excessively low and excessively high cognitive loads reduce task performance [?]. Many factors affect cognitive load, such as prior knowledge, experience, and working memory capacity, which typically need to be controlled in research [?]. Common methods for controlling cognitive load include controlling task difficulty, task complexity, and time pressure. Since readers' goal in using digital libraries is to improve information service efficiency, this study selects time pressure as the technical means to control cognitive load.

3.2 Navigation Structure

The importance of navigation functions for website and APP development is self-evident. Any webpage navigation has three functions: (1) providing users with a method to jump between websites; (2) navigation design must convey the relationship between navigation elements and their target content; (3) navigation design must convey the relationship between navigation content and users' current browsing page [?]. The important mission of navigation is to clearly tell users “where they are” and “where they can go.” Therefore, whether the logical structure of navigation is clear is crucial for users to successfully complete tasks and avoid getting lost.

Navigation structures were initially dominated by flat structures. As website information volume increased, navigation structures gradually evolved from flat structures to tree-shaped navigation structures. The National Digital Library of China APP selected for this study has two versions: the old version features a typical flat structure, while the new version features a tree-shaped structure, as shown in [Figure 1: see original paper].

3.3 Emotional Experience and Usability Measurement

Emotion is a “barometer” of individual psychological states, and life events are important prerequisites for daily emotional experience [?]. A.J. Zautra et al. believe that all emotional experiences occur in certain contexts, that emotional experiences dynamically change with life events, and that the impact of life events on emotional experiences can be divided into positive and negative categories [?]. Digital reading is also a life event. According to Zautra' s emotional experience theory, readers will experience certain emotional fluctuations after completing tasks, which can be divided into positive and negative directions. This study uses the classic PANAS (Positive and Negative Affect Schedule) to measure emotional experience. The scale consists of 20 adjectives, including 10 positive emotion words and 10 negative emotion words. The scale can be used to describe both long-term and immediate emotional states with high reliability and validity [?].

Usability measurement employs the classic SUS (System Usability Scale) [?]. The scale consists of 10 questions addressing system ease of use, usefulness, self-efficacy, and satisfaction, forming a comprehensive system usability score. The total score is 100, with scores below 50 indicating unacceptable usability, 51-70 indicating marginal acceptability, and scores above 71 indicating good usability.

3.4 Research Hypotheses

Based on the above theories, this study proposes the following hypotheses:

Hypothesis 1: Cognitive load may have significant effects on emotional experience, usability, and task performance.

Hypothesis 2: Navigation structure may have significant effects on emotional experience, usability, and task performance.

Hypothesis 3: Cognitive load and navigation structure may have interactive effects on emotional experience, usability, and task performance.

Hypothesis 4: There may be significant correlation between usability and emotional experience changes.

Hypothesis 5: Flat navigation structure may be more suitable for elderly users.

Experimental Process and Data Acquisition

4.1 Experimental Design

This study employed a 2$×$2 mixed experimental design (two factors, two levels each). The two factors were cognitive load and navigation structure. Cognitive load was divided into high and low levels, controlled using time pressure technology as a between-subjects factor. Navigation structure was divided into flat structure and tree structure, corresponding to the new and old versions of the National Digital Library of China APP, as a within-subjects factor.

The NASA-TLX (NASA Task Load Index) is the most commonly used scale for measuring cognitive load, consisting of three questions with mean calculation. Each question uses a 7-point Likert scale [?]. In this study, time pressure settings and cognitive load measurement methods were as follows: Before the experiment, five readers were invited to complete five predetermined tasks sequentially, and the average time consumed was calculated. Using the NASA-TLX scale, the corresponding cognitive load value was measured. Without time pressure, the cognitive load score was approximately 4.0. Based on the average consumption time, $±$60 seconds were applied, and five readers were again invited to complete the predetermined tasks. The measured cognitive load values were approximately 3.3 and 6.1, respectively. Accordingly, these time settings were designated as low and high time pressure conditions, corresponding to low and high cognitive load conditions. In this study, the corresponding task time limits were 300 seconds and 180 seconds. Exceeding the time limit was considered task failure.

4.2 Experimental Participants and Grouping

This study invited 20 elderly participants, all recruited from a university for the elderly. All had education levels above high school, with an average age of 64.37 years (SD = 4.03), including 9 males and 11 females. Participants used mobile phones for reading an average of more than 3 hours per day, had normal corrected vision, and were right-handed. All participants carefully read and signed the informed consent form before the experiment.

According to the mixed experimental design, the 20 elderly participants were evenly divided into two groups (high cognitive load group and low cognitive load group), with 10 participants in each group. Each participant needed to complete two experimental tests, performing tasks in both flat navigation and tree navigation structures.

4.3 Experimental Tasks and Data Collection

Each participant needed to complete the same number of tasks with similar content in both versions of the National Digital Library of China APP, as shown in . Participants were required to complete tasks sequentially within the specified time, and experimenters recorded the completion time for each task. To eliminate order effects, each participant randomly drew the experimental version order for the digital library. In the low cognitive load group, the number of participants proceeding from Interface A to Interface B was equal to those proceeding from Interface B to Interface A (5 each). In the high cognitive load group, 4 participants proceeded from Interface A to Interface B, and 6 participants proceeded from Interface B to Interface A.

Upon entering the laboratory, participants rested for 3-5 minutes, listened to an introduction about the experimental content and requirements, and completed the PANAS emotion scale before the experiment began to record their baseline emotional state. After completing the test tasks for one version, they completed the PANAS scale again and filled out the SUS scale. The interval between testing the two versions was 30 minutes, with each participant requiring approximately 40-50 minutes to complete all tests. The experimental device was a Huawei Nova 2 smartphone with a 6-inch screen, resolution of 2160$×$1080, uniform brightness, and standardized lighting conditions.

Two sets of data were collected during the experiment: objective data and subjective data. Objective data referred to behavioral data, including task completion time and task success rate. To accurately measure task completion time, the experiment used Dikablis glasses-style eye-tracking equipment with a sampling rate of 60Hz, and data analysis employed the D-Lab data analysis system. Subjective data included emotional experience data and usability data, collected using the PANAS and SUS scales respectively, with data analysis performed using Stata 14.0.

Research Results

5.1 Behavioral Data Results

After the experiment, participants' average task completion times and success rates were statistically analyzed, with results shown in . Task 1 required the longest average completion time, while Tasks 2 and 3 required similar times, slightly less than Task 1. Tasks 4 and 5 required the least time.

A two-way ANOVA on task time revealed a significant interaction effect between cognitive load and navigation structure on Task 1 completion time ($F = 4.88$, $p = 0.035$), but no significant main effects of cognitive load or navigation structure on Task 1 completion time ($p > 0.05$). Navigation structure had significant main effects on Task 3 ($F = 4.12$, $p = 0.05$) and Task 5 ($F = 6.5$, $p = 0.02$) completion times. In this experiment, Task 1 completion time only changed when both cognitive load and navigation structure changed simultaneously, not when either variable changed alone. Task 3 and Task 5 completion times changed significantly with navigation structure changes.

Chi-square tests on Task 4 and Task 5 success rates showed significant main effects of cognitive load on Task 4 ($^2 = 7.57$, $p = 0.006$) and Task 5 ($^2 = 15.18$, $p < 0.001$) success rates, indicating that success rates for these tasks changed significantly with cognitive load. Navigation structure had no significant effect on task success rates. Detailed results are shown in .

Simple effects analysis of the interaction between cognitive load and navigation structure on Task 1 completion time revealed that when the flat navigation structure was fixed, task completion time decreased from low to high cognitive load conditions, indicating that time pressure helped elderly readers complete tasks faster in flat navigation. When the tree navigation structure was fixed, task completion time increased from low to high cognitive load conditions, indicating that elderly readers were more affected by time pressure when completing tasks in tree navigation structures, where time pressure prolonged task completion time. This is illustrated in [Figure 2: see original paper].

5.2 Emotional Experience Results

Emotional experience was examined by measuring change scores (post-test minus pre-test). Before the experiment, participants' baseline emotional states were measured, yielding pre-test values for positive affect (PA1) and negative affect (NA1). After completing each APP test, post-test emotional state measurements were immediately taken, resulting in PA2 and NA2. The difference between the two positive affect scores represented the change in positive emotional experience, with negative emotional experience calculated similarly. Descriptive statistics for emotional experience measurements are shown in .

Visualizing the emotional experience data, as shown in [Figure 3: see original paper], revealed that under high cognitive load with flat navigation, positive emotional experience increased (PA = 0.48) while negative experience decreased (NA = -0.19). Both high cognitive load with tree navigation and low cognitive load with flat navigation decreased readers' positive emotional experience, with high load tree navigation substantially reducing positive emotional experience (PA = -0.89) while slightly increasing negative emotions (NA = 0.11). Low load tree navigation had minimal impact on both positive and negative emotional experiences.

Further analysis of the effects of cognitive load and navigation structure on emotional experience changes used positive emotional experience change as the dependent variable in a two-way ANOVA. The results showed a marginally significant main effect of navigation structure on positive emotional change ($F = 3.88$, $p = 0.058$), no significant main effect of cognitive load ($F = 0.18$, $p = 0.677$), but a significant interaction effect between cognitive load and navigation structure on positive emotional change ($F = 13.66$, $p < 0.001$). This indicates that only when both independent variables act together do they significantly affect emotional experience change.

After confirming the interaction effect, simple effects analysis revealed that with navigation structure fixed, flat navigation structure showed increased positive emotions with increased cognitive load, while tree navigation structure showed decreased positive emotions with increased cognitive load. With cognitive load fixed, under low cognitive load conditions, the difference in positive emotional experience between the two navigation structures was minimal, though tree navigation structure was slightly higher. Under high cognitive load conditions, the difference in emotional experience was significant, with flat navigation structure yielding higher positive emotional experience. This is illustrated in [Figure 4: see original paper].

Further analysis of the effects of cognitive load and navigation structure on negative emotional experience changes used negative emotional experience change as the dependent variable in a two-way ANOVA. The results showed no significant effects of cognitive load ($F = 0.55$, $p = 0.47$) or navigation structure ($F = 2.2$, $p = 0.14$) on negative emotional experience changes, and no interaction effect ($F = 0.02$, $p = 0.89$).

5.3 Usability Results

After completing the APP test tasks, participants first rated their emotional experience and then evaluated product usability. Descriptive statistics for usability scores under the four test conditions are shown in .

A box plot of usability scores under the four conditions is shown in [Figure 5: see original paper]. Flat navigation structure usability scores were slightly higher than tree navigation structure scores, with similar usability score distributions across the two cognitive load conditions. Further two-way ANOVA on usability scores revealed no significant effect of cognitive load on usability scores (F = 0.07, p = 0.79), but a significant effect of navigation structure on usability (F = 7.99, p = 0.009). The interaction between cognitive load and navigation structure was not significant (F = 3.33, p = 0.079).

5.4 Relationship Between Usability and Emotional Experience

To test the theoretical hypothesis that usability correlates with emotional experience changes, Pearson correlation analysis was conducted among usability scores, positive emotional experience change scores, and negative emotional experience change scores. The results showed significant correlation between positive and negative emotional experience changes (r = -0.493, p = 0.005), but no significant correlation between positive emotional experience changes and usability scores (r = 0.323, p = 0.076) or between negative emotional experience changes and usability scores (r = -0.137, p = 0.462).

Discussion and Analysis

Digital reading user experience is a complex psychological activity. By examining readers' performance and subjective evaluations, we can partially quantify and assess this activity, effectively analyzing the development and changing psychological processes of user experience. This provides theoretical guidance for digital library interface design, product development, and service model innovation, improving information resource utilization and promoting nationwide reading. User-centered design theory posits that whether user interface design is friendly and reasonable directly affects digital library system efficiency [**?**]. This study investigated emotional experience and usability from two dimensions: cognitive load and navigation structure. The experimental results are discussed below in relation to the research hypotheses.

6.1 Effects of Cognitive Load on Task Performance, Emotional Experience, and Usability

Behavioral data analysis showed that cognitive load had no significant effect on completion time for any of the five tasks but significantly affected success rates for Task 4 (F = 7.57, p = 0.006) and Task 5 (F = 15.18, p < 0.001). Under high time pressure conditions, success rates for Tasks 4 and 5 were lower than under low time pressure conditions (see for detailed results). This finding is similar to Li Jing et al.' s research, which examined the effects of high, medium, and low time pressure conditions on users' memory for graphics or colors, finding that greater time pressure led to poorer cognitive speed and effectiveness [**?**]. Previous research has shown that pressure increases information processing speed but causes people to focus on general outlines rather than in-depth analysis during information processing [?], suggesting that time pressure affects task completion time.

In this study, all participants used the National Digital Library of China for the first time. Under high time pressure conditions, Task 1 completion time was much longer than for other tasks. Data in show that completion speed gradually accelerated for subsequent tasks, indicating that users spent considerable time learning the software during the initial task stage. The question arises: Does time pressure significantly affect learning time during the initial task stage? Experimental results showed that time pressure had no significant effect on Task 1 completion time (F = 0.48, p = 0.9), but there was an interaction effect between time pressure and navigation structure (F = 4.88, p = 0.035). This suggests that neither factor alone had much effect on Task 1 completion time; only when both factors acted together did they exert significant influence.

Emotional experience data analysis showed that cognitive load had no significant effect on positive emotional changes (F = 0.18, p = 0.677) or negative emotional experience changes (F = 0.55, p = 0.47). Previous research suggests that high pressure may cause unpleasant changes in physiology, emotion, and cognition, and may lead to anxiety and other negative emotions [?]. However, this study did not find significant effects of cognitive load on emotional experience changes. Further analysis of the interaction between cognitive load and navigation structure revealed an interactive effect on emotional experience changes, indicating that cognitive load' s effect on emotional experience requires joint action with navigation structure. Simple effects analysis found that when time pressure combined with tree navigation, increased time pressure not only failed to effectively improve Task 1 completion speed but also had a reverse inhibitory effect.

Usability data analysis showed that cognitive load had no significant effect on usability scores (F = 0.07, p = 0.79). Post-test interviews indicated that participants were confident they could proficiently use the National Digital Library of China, having become familiar with the product through completed tasks, and made comprehensive evaluations accordingly. In summary, cognitive load significantly affected task success rates in task performance but required joint action with navigation structure to affect Task 1 completion time and emotional experience. It had no significant effect on usability.

6.2 Effects of Navigation Structure on Task Performance, Emotional Experience, and Usability

Experimental results showed that navigation structure had no significant effect on task success rates but significantly affected completion times for Task 3 (F = 4.12, p = 0.05) and Task 5 (F = 6.5, p = 0.02), and jointly affected Task 1 completion time with cognitive load. Further analysis revealed that task completion time in flat navigation structure was less than in tree navigation structure, indicating that elderly users completed tasks more easily and efficiently in flat navigation structures. The function of website navigation is to guide and help users quickly find needed functions. Different navigation structures have different information transmission hierarchies. Previous research has shown that elderly users perform better with linear navigation structures than hyperlink navigation forms. D. Castilla et al. tested email system navigation for elderly users, asking them to receive and send emails through linear navigation or hyperlink navigation, finding that linear navigation had better success rates and efficiency than hyperlink navigation [?]. In this study, the old version of the National Digital Library of China APP used a flat navigation structure belonging to linear navigation forms, while the new version belonged to hyperlink navigation. Linear navigation requires step-by-step operation without skipping, whereas hyperlink navigation allows direct searching and jumping to needed pages. Due to insufficient computer familiarity and reduced cognitive speed and memory, elderly users more readily accept linear navigation.

Positive emotional experience changes were significantly affected by navigation structure ($F = 3.88$, $p = 0.058$), and the joint effect with cognitive load significantly influenced positive emotional experience changes ($F = 13.66$, $p < 0.001$). Navigation structure's significant effect on positive emotional experience changes may be because when users cannot find corresponding functions, frustration increases, but when navigation effectively guides users to needed functions, users experience positive emotions such as pleasure, happiness, and confidence. As shown in [Figure 3: see original paper], flat navigation structure significantly increased positive emotions (PA = 0.48) and slightly decreased negative emotions (NA = -0.19) when helping users find functions. Users may get lost in tree navigation, resulting in significantly decreased positive emotions (PA = -0.89) and slightly increased negative emotions (NA = 0.11). The interaction between cognitive load and navigation structure revealed that under low cognitive load, both navigation structures had minimal impact on emotional experience, with change values in the range (-0.5, 0.5). However, under high cognitive load, the impact of the two navigation structures on emotional experience was amplified, as shown in [Figure 4: see original paper]. Therefore, this study found that navigation structure has a substantial impact on elderly users' emotional experience, with cognitive load playing a moderating role.

Usability data analysis found that navigation structure significantly affected usability ($F = 7.99$, $p = 0.009$), with flat navigation structure receiving higher usability scores than tree navigation structure. As previously mentioned, navigation plays a very important role in digital library use. Clear navigation structure not only helps improve usability but also increases users' positive emotional experience. Therefore, navigation structure selection is crucial for enhancing digital library user experience across different populations. In summary, navigation structure significantly affected task completion time, significantly influenced positive emotional experience changes, and showed significant interaction with cognitive load on positive emotions. Navigation structure significantly affected usability. The interaction between cognitive load and navigation structure was only significant for Task 1 completion time and positive emotional experience changes.

6.3 Other Influences

As mentioned above, correlation analysis between usability scores and positive/negative emotional experience change values showed no significant correlation between usability and emotional changes. This indicates that under the two cognitive load conditions in this study, as navigation structure changed, positive emotional changes did not significantly co-vary with usability scores, and the same was true for negative emotional changes. However, there was a significant negative correlation between positive and negative emotional experiences, indicating that when positive emotional experience increased, negative emotional experience decreased. In digital library emotional experience research, enhancing positive emotional experience or reducing negative emotional experience both help improve users' overall emotional experience. It should be noted that task completion order also affected emotional experience changes in this study. Since the same task order was used, this order may be one potential factor causing emotional experience changes.

Combining the above conclusions, it is evident that elderly users had significantly higher task efficiency, positive emotional experience change values, and usability scores when using digital libraries with flat navigation structure compared to tree navigation structure, indicating that flat navigation structure is more suitable for elderly users. When providing services for this population, digital libraries should adopt flat navigation structure. The National Digital Library of China has already developed two versions of its APP and should update them synchronously, developing corresponding information service models and content for different user groups to better promote nationwide digital reading. Finally, enhancing emotional experience helps retain readers, increase reading frequency and duration, and improve information resource utilization. Digital library development should emphasize not only usability but also users' emotional experience.

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Author Contributions

Hou Guanhua: Data processing and analysis, paper writing;
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Note: Figure translations are in progress. See original paper for figures.