HSM-Based Study on Influencing Factors and Configurational Effects of Mobile Search Behavior (Postprint)

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Abstract

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Full Text

Preamble

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Research on Influencing Factors and Configuration Effects of Mobile Search Behavior Based on HSM

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Abstract:
[Purpose/Significance] Grounded in the Heuristic-Systematic Model (HSM), this study investigates the influencing factors and configuration effects of mobile search behavior. [Method/Process] User data were collected through questionnaires, and structural equation modeling (SEM) combined with fuzzy-set qualitative comparative analysis (fsQCA) were employed to explore heuristic and systematic influencing factors and their configurations affecting mobile search behavior. [Results/Conclusion] SEM results indicate that source credibility, search ease, and content relevance serve as antecedents for both heuristic and systematic mobile search behaviors, while content accuracy shows no significant effect on either. fsQCA results reveal two distinct patterns of mobile search behavior: a labor-saving search mode under limited conditions and an effective search mode driven by task demands. This study uncovers the complex influence mechanisms of mobile search behavior, providing guidance for improving mobile search services and optimizing user search strategies.

Keywords: heuristic search; systematic search; influencing factors; configuration effect
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The widespread adoption of mobile internet and smartphones has gradually shifted user search behavior from PC to mobile devices. Mobile phones have become the primary device for search engine users. As of December 2020, mobile search users reached 768 million, with 97.1% of search engine users conducting searches via mobile devices, surpassing PC-based search service usage. Mobile search is not simply a transplantation of PC search but constructs a new information search ecosystem through diversified search entry points and application scenarios. On one hand, search entry points and methods have diversified—users can access search engines through browser apps, built-in mobile browsers, or dedicated search engine apps to search for text, images, voice, and QR codes. Mobile search scenarios have also become richer and more refined, with significant variations in information content and result rankings when users search during work, study, entertainment, fitness, or travel. On the other hand, as major internet service providers continue to expand their search business and improve search functionalities, search products have made substantial improvements in search efficiency, intelligence, service personalization, and result accuracy, continuously optimizing user experience. In an environment of search-as-a-service and instant search results, users tend to obtain information through simple, convenient methods, only expending more effort and time when necessary.

Mobile search behavior patterns align fundamentally with the Heuristic-Systematic Model (HSM). To minimize cognitive effort or maximize benefits, users select search behavior patterns based on personal motivation, ability, information characteristics, and sources. When users have strong confidence in search results, they adopt simple search strategies requiring less cognitive effort and lower ability levels. When users perceive greater uncertainty in search

results, they employ complex search strategies demanding more cognitive effort and higher ability levels. These two search behaviors are termed heuristic search and systematic search, respectively—the former relies on intuitive judgment of information external features, while the latter emphasizes rational evaluation of information content. HSM serves as a general framework and basic paradigm for behavioral decision-making research, unrestricted by specific variables and relationships in fixed models, better aligning with people's free, flexible, and complex thinking patterns, and effectively explaining mobile search behavior decisions and path influences. This study adopts HSM as its theoretical framework, combining SEM and fsQCA to identify influencing factors of heuristic and systematic mobile search behaviors, explore multiple combinations of these factors, theoretically reveal the characteristics and patterns of mobile search behavior, enrich mobile search research, and practically provide reliable guidance for improving mobile search products and services and enhancing search experiences for different user types.

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2 Research Foundation

2.1 Related Research on Mobile Search Behavior

Mobile search behavior, as a common user information behavior, has received widespread attention. Research themes have focused on mobile search characteristics and its differences from PC search in query terms, search time, click behavior, and result judgment, while also examining influencing factors of specific search behaviors and intentions, including mobile medical information search, mobile academic information search, mobile visual search, and cross-screen behavior in mobile search contexts. Methodologically, scholars have employed logs, experiments, questionnaires, and interviews to investigate mobile search patterns, behavioral characteristics, and influencing factors. For instance, M. Kamvar et al. tracked user query behavior through Google mobile search logs to understand mobile users' query content, duration, results, and click frequency. Zhang Min et al. used screen recording experiments to capture mobile medical information search behavior characteristics under different task contexts. L. Cilliers et al., grounded in the UTAUT model, used questionnaires to identify factors promoting students' active use of mobile phones for health information.

Theoretically, most studies have employed classic information system models such as TAM, TPB, TTF, and ECM-ISC to explore the effects of existing variables on mobile search behavior. However, these studies have not differentiated search behavior patterns, and due to differences in research contexts and subjects, empirical conclusions using the same theoretical models vary significantly. For example, subjective norm—a key component of TPB referring to perceived social pressure—is found by Z.H. Yang et al. to positively influence consumers' mobile information-seeking intention when facing food safety risks, while Chen Minghong et al. find it has no significant effect on either male or female users'

mobile search intention. These inconsistencies suggest that while existing research covers rich content and diverse methods, theoretical frameworks contain relatively fixed variables that have yet to reveal universal characteristics and influence paths of mobile search behavior, necessitating systematic and in-depth investigation.

In different mobile search contexts, users select the most appropriate behavior patterns based on information needs, search ability, search tasks, and cognitive resources.

2.2 HSM and Its Application Research

The Heuristic-Systematic Model (HSM), proposed by S. Chaiken in 1980 through heuristic-systematic persuasion experiments, is an information processing theory and one of the most widely applied dual-process models in social psychology, capable of explaining how users accept and process persuasive information. HSM posits that information processing includes two parallel behavioral modes: heuristic and systematic. Heuristic-based individuals rely on simple, non-content information cues for decision-making, while systematic individuals conduct comprehensive consideration of information content before making decisions. Some scholars have begun applying HSM to search behavior research. For example, M. Zarró used HSM to analyze exploratory information search behavior and user cognitive processes, proposing that users prefer heuristic processing in initial search stages and shift toward systematic processing as search progresses and cognition deepens. Zhao Chao treated information searching and browsing as heuristic and systematic behaviors, respectively, exploring how user involvement and confidence affect both. Huang Liqiang et al. demonstrated through experiments that search engine users' click behavior on product search results exhibits both heuristic and systematic patterns, with behavior modes changing according to user knowledge, experience, and needs. These studies show HSM possesses strong explanatory power and applicability for search behavior research, objectively reflecting users' perceptual and rational cognition during actual searches, and revealing objective patterns unconstrained by fixed models.

In summary, human thinking is complex—sometimes simple, sometimes meticulous—and changes according to context or mood. Consequently, mobile search behavior is not a single behavioral trajectory but sometimes involves simple information processing decisions and other times rational judgments based on careful consideration, representing a coexistence of heuristic and systematic patterns. However, existing mobile search behavior research is often limited by traditional information system frameworks and fails to adequately address mobile search uniqueness and user psychological needs. HSM's flexibility provides favorable support for broader research needs, making it more suitable for analyzing mobile search behavior by reflecting users' intersecting perceptual and rational cognitive patterns and presenting the distinct yet interconnected relationship between heuristic and systematic search behaviors.

This study adopts HSM as its theoretical framework, dividing mobile search behavior into heuristic and systematic modes based on decision conditions. It examines information content accuracy and relevance, source credibility, and search ease as influencing factors. Building on SEM analysis, it employs fsQCA to deeply explore multi-factor combination paths of mobile search behavior, expanding research on mobile search behavior influence mechanisms through exploring relationships among information cues.

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3 Research Design

3.1 Research Model

HSM can be applied to information processing activities in broader contexts, demonstrating strong adaptability in explaining user information decision-making behavior in mobile internet environments. HSM emphasizes the coexistence and interaction of heuristic and systematic information processing decisions, aligning with users' complex thinking patterns where perception and rationality coexist during mobile search. It can also explain cognitive and behavioral biases caused by interactions among information cues, providing a reliable foundation for explaining the complexity of mobile search behavior.

Therefore, this study adopts HSM as its theoretical framework (Figure 1 [Figure 1: see original paper]). Based on users' elaboration level in processing information, external influencing factors are selected: source credibility and search ease serve as heuristic cues, while content accuracy and content relevance serve as systematic cues, exploring how these internal and external cues influence heuristic and systematic mobile search behaviors.

3.2 Research Hypotheses

Previous studies have classified cues according to cognitive effort, generally treating external factors requiring less cognitive cost as heuristic cues (e.g., information quantity, source credibility, information richness) and internal factors requiring more cognitive cost as systematic cues (e.g., information topic, content, relevance). Following this classification, this study treats source credibility and search ease as heuristic cues for mobile search behavior, and content accuracy and relevance as systematic cues.

3.2.1 Effects of Heuristic Cues on Mobile Search Behavior Source credibility and search ease belong to heuristic information processing characterized by simple decision-making, low cognitive cost, and non-content cues. Source credibility triggers a "credible means correct" rule, facilitating evaluation of information effectiveness from more credible sources. Since S. Chaiken proposed HSM, this has received consistent recognition from scholars. Search ease refers to decision-making based on perceived search task difficulty and sys-

tem usability, aligning with intuitive thinking patterns and heuristic processing that minimizes cognitive effort.

Source Credibility. Source credibility (CRE) refers to users' perception of source reliability and serves as a peripheral path affecting adoption intention. In user behavior research across online consumption, healthcare, and social media, source credibility is typically validated as an important heuristic cue. Research shows that highly credible sources significantly influence information decision-making, particularly prominent in mobile search behavior. With abundant online information from diverse sources, users struggle to quickly and accurately identify information quality. Credible sources can reduce information search and analysis costs, positively promoting search behavior. Therefore, users' perception of source credibility importantly influences mobile search behavior. The following hypotheses are proposed:

- H1a: Higher source credibility more readily triggers heuristic mobile search behavior.
- H1b: Higher source credibility more readily triggers systematic mobile search behavior.

Search Ease. In mobile search, perceived ease of use (PEU) refers to users' perception of how easy it is to use mobile search, representing a primary factor affecting search intention and behavior. When users perceive search difficulty exceeding acceptable ranges, their search motivation decreases. Conversely, when users believe they can use search engines with minimal effort, their search behavior becomes more active. Generally, users evaluate ease of use based on search tool usability, functional convenience, operational simplicity, and personalized services, expecting to complete search tasks with minimal cost and effort. As a heuristic search cue, search ease positively influences both search behaviors:

- H2a: Higher search ease more readily triggers heuristic mobile search behavior.
- H2b: Higher search ease more readily triggers systematic mobile search behavior.

3.2.2 Effects of Systematic Cues on Mobile Search Behavior Systematic cues primarily involve content features requiring substantial cognitive effort and elaborative information processing, making information content quality a typical systematic cue. This study examines content quality through accuracy and relevance dimensions.

Content Accuracy. Content accuracy (ACC) refers to the degree to which information content aligns with objective reality. More accurate information is more readily accepted by users. However, diverse information sources, proliferation of false information, and information loss during dissemination greatly reduce content accuracy, affecting users' search result judgments. In mobile search, content accuracy directly influences search behavior. When users must

expend considerable effort judging information authenticity, completeness, and reliability, their search enthusiasm decreases and search result uncertainty increases. Therefore, content accuracy may relate to search behavior as follows:

- H3a: Higher content accuracy more readily triggers heuristic mobile search behavior.
- H3b: Higher content accuracy more readily triggers systematic mobile search behavior.

Content Relevance. Content relevance (REL) represents users' judgment of the match between obtained information and their information needs. When users discover information content relevant to their search task during searching or browsing, they consider it relevant. Content relevance is one of information's value characteristics—only information relevant to user needs can attract attention. When encountering irrelevant information, users tend to selectively avoid it or shift to information matching their needs. Compared to PC search behavior, mobile search users hope to obtain the most relevant information in the shortest time, expecting target information to rank as high as possible in search results. Thus, content relevance is particularly important in mobile search behavior, with the following hypothesized relationships:

- H4a: Higher content relevance more readily triggers heuristic mobile search behavior.
- H4b: Higher content relevance more readily triggers systematic mobile search behavior.

3.3 Questionnaire Design and Data Collection

To ensure content validity, the questionnaire was designed based on existing literature, with items adapted and modified according to the research context (Table 1). Antecedent variables each contained 4 items, while outcome variables included 2 or 3 items, all measured on a 7-point Likert scale. Given Baidu's 90.9% penetration rate among search engine users and college students' high proportion among Chinese internet users, the survey targeted college students using mobile Baidu. The questionnaire was created on Wenjuanxing platform and distributed via WeChat, yielding 304 responses. Basic demographics of mobile search users are shown in Table 2 : 47.4% male and 52.6% female; 36.2% used Baidu Browser APP, 25.7% used Baidu APP, and 62.8% used other apps (e.g., UC Browser or built-in browsers) for Baidu searches. Search content included academic, technological, entertainment, and various other information types. Over 70% of users had used mobile Baidu search for more than three years, with usage frequency reaching once or multiple times daily.

4 Structural Equation Model Analysis

4.1 Measurement Model

SmartPLS software was used to analyze reliability and validity of source credibility, search ease, content accuracy, content relevance (four antecedents), and heuristic and systematic mobile search behaviors (two outcomes). Reliability was assessed using Average Variance Extracted (AVE), Composite Reliability (CR), and Cronbach's Alpha, with critical values of 0.50, 0.70, and 0.70, respectively. Validity was measured using Fornell and Larcker's discriminant validity method. Results are shown in Tables 3 and 4 .

Table 3 shows all factor loadings exceed 0.7, with AVE values between 0.6 and 0.9 and high CR and Cronbach's Alpha values, indicating strong internal consistency and high questionnaire reliability. Table 4 validity results show that the square root of each variable's AVE exceeds its correlations with other latent variables, demonstrating good discriminant validity.

4.2 Structural Model

Based on measurement model assessment, regression coefficients (β) and significance (p) were calculated to test hypotheses. Structural model results are shown in Figure 2 [Figure 2: see original paper].

1. **Heuristic Cues:** Source credibility positively affects both heuristic and systematic mobile search behaviors ($\beta = 0.114$, $p < 0.05$; $\beta = 0.128$, $p < 0.01$). Search ease demonstrates highly significant positive effects on both behaviors ($\beta = 0.123$, $p < 0.001$; $\beta = 0.274$, $p < 0.001$). Thus, H1a, H1b, H2a, and H2b are supported.
2. **Systematic Cues:** Content accuracy has minimal impact on both mobile search behaviors. However, content relevance shows highly significant positive effects ($\beta = 0.229$, $p < 0.001$ for heuristic; $\beta = 0.167$, $p < 0.001$ for systematic). Therefore, H3a and H3b are not supported, while H4a and H4b are supported.

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5 Fuzzy-Set Qualitative Comparative Analysis

While SEM effectively validated linear relationships between external cues and heuristic-systematic search behaviors, it failed to reveal "joint effects" among external cue variables on search behavior, exhibiting linear, singular causality. To address this limitation, this study introduces fsQCA to explore multiple concurrent causal relationships and asymmetrical relationships from a set-theoretic perspective, deepening understanding of different factor configurations.

5.1 Data Calibration

fsQCA integrates category and degree of set membership, possessing both qualitative and quantitative attributes, enabling more comprehensive and precise analysis of outcome occurrence paths and the importance of each condition in configurations. Calibration is the first step in fuzzy-set analysis, assigning set membership degrees to variables. Since fsQCA applies to single-item variables while this study uses multi-item scales, arithmetic means were calculated for each variable before calibration. Following Rihoux's standards, 0.95, 0.5, and 0.05 serve as full membership, crossover, and full non-membership points, respectively. Likert 7-scale values were converted to [0,1] membership scores using (7,4,1) anchors. For basic information variables (usage duration and frequency), (0.95,0.5,0.05) calibration was similarly applied, with long duration/high frequency as full membership and short duration/low frequency as full non-membership. Gender was calibrated using 0.05 (full non-membership) and 0.95 (full membership) standards, with females calibrated as 0.95 and males as 0.05.

5.2 Necessity Analysis

Before configuration analysis, necessity of each antecedent condition must be tested—a crucial prerequisite for truth table construction. From set theory, Ragin proposes two key concepts and metrics: consistency and coverage. In necessity analysis, consistency measures the degree to which condition set Xi is included in outcome set Yi, calculated as the proportion of Xi values exceeding corresponding Yi values (Formula 1). When consistency reaches 0.9, the condition is necessary. Coverage represents Xi's explanatory power for Yi (Formula 2).

Using fsQCA software, necessity analysis was conducted separately for heuristic and systematic mobile search behaviors. Table 5 shows single-condition consistency and coverage. Among basic information variables, high usage frequency achieves consistency of 0.90 and 0.91. Among information cue variables, high search ease achieves consistency of 0.93 and 0.95, both exceeding 0.9. This indicates usage frequency and search ease are necessary conditions for mobile search behavior—these must be present in configurations, otherwise the outcome will not occur. Other antecedents show consistency below 0.9, indicating they are not necessary conditions. To select sufficient but non-necessary conditions for configurations, configuration analysis is required.

5.3 Antecedent Configuration Analysis

Truth table analysis was conducted to examine sufficient paths to outcomes, with frequency threshold set at 1 and consistency threshold at 0.8 (PRI consistency threshold at 0.75). Based on SEM validation, three complex causal models of mobile search behavior were constructed using three basic characteristic variables and four external cue variables. Model C's many condition

variables generated numerous configurations; to filter effective configurations, its frequency threshold was increased to 2.

Results produce three solution types: complex, intermediate, and parsimonious. The intermediate solution incorporates "easy" logical remainders with theoretical and practical support, while the parsimonious solution may involve "difficult" remainders detached from case reality. Results show intermediate and complex solutions are identical, suggesting no "easy" counterfactual cases exist. Table 6 presents the intermediate/complex solution.

Model A includes three basic characteristics (gender, usage duration, frequency), generating two configurations each for heuristic and systematic behaviors with high consistency but limited case coverage.

Model B comprises two heuristic cues (source credibility, search ease) and two systematic cues (content accuracy, relevance). Table 6 shows identical configurations for both search behaviors with similar effects.

Model C combines three basic characteristics with four external cues, yielding three shared configurations for both behaviors with high consistency and coverage.

For basic characteristics, usage frequency is most significant—present in every configuration across Models A and C, indicating high-frequency users have formed fixed search habits or strategies with specific preferences for heuristic or systematic search. Gender also affects mobile search behavior, with different genders considering task complexity and strategies differently. Model C's H8/S8 and H9/S9 show that female users focus more on search ease and prefer heuristic strategies, while male users comprehensively consider all cues and prefer systematic strategies. Usage duration shows inconsistent directionality across Models A and C, suggesting it is influenced by other factors and has some uncertainty.

For external cues, search ease is most prominent—present in all configurations except H5/S5 in Model B, indicating it is unaffected by other variables and constitutes a key element for both search behaviors regardless of user groups, information quality, tasks, or environments. Source credibility, content accuracy, and relevance show consistent directional effects in Model B (high relevance, low credibility, low accuracy interacting with high search ease). However, in Model C, these three variables show inconsistent directional effects under gender, duration, and frequency influences, exhibiting uncertainty and complex causality.

Model B represents the "HSM-based mobile search behavior model"—this study's research model. To further explore causal relationships, Table 7 illustrates influence paths. Both behaviors output four intermediate/complex solutions and two parsimonious solutions with identical triggering paths: (1) high search ease × low content accuracy; (2) high search ease × low source credibility; (3) high search ease × high content relevance. These can be summarized as two patterns:

1. **Labor-Saving Search Mode Under Limited Conditions:** Constrained by low content accuracy or low source credibility, this mode operates in poor mobile search environments lacking reliable channels and accurate information. With limited information cues, this pattern centers on high search ease, expecting minimal effort for searching, focusing on usability evaluation rather than deep content analysis, exhibiting distinct heuristic characteristics.
2. **Effective Search Mode Driven by Task Demands:** In specific search tasks with clear demand orientation, this mode centers on high content relevance as the core condition, driven by the necessary condition of high search ease, constituting an effective mobile search mode that strives to quickly and accurately obtain effective information to complete tasks, demonstrating both heuristic and systematic characteristics.

5.4 Predictive Validity

To test the model's predictive power, fsQCA configurations were examined across different samples. First, the sample was randomly split into two equal subsamples (Sample 1: n=152, Sample 2: n=152). Sample 1 analysis yielded highly similar configurations to the full sample (Table 8). Sample 2 was then used to test Sample 1's configurations, with each configuration represented by its minimum variable. Table 8 shows highly similar results across subsamples, confirming the HSM-based mobile search behavior model's strong predictive applicability across datasets. XY plots for M1 and N3 demonstrate high consistency, coverage, and asymmetrical relationships.

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6 Research Analysis and Conclusions

6.1 Discussion

This study, grounded in HSM and employing SEM and fsQCA from quantitative and qualitative perspectives, explores influencing factors and configuration effects of heuristic and systematic cues on mobile search behavior, yielding the following conclusions:

1. **Mobile search behavior follows the principle of least effort.** Search ease significantly and positively affects both heuristic and systematic search behaviors, representing a necessary condition for mobile search behavior and an essential component of any influence path. fsQCA reveals Pattern 1 as the most labor-saving path—users decide whether to search based solely on search ease. When search difficulty increases, user willingness is substantially affected. Pattern 2 represents an effective path where users search for relevant information based on search ease. Overall, mobile search follows the principle of minimal effort—users consistently seek to expend minimal effort and cost for optimal results.

2. **Mobile search behavior conforms to bounded rationality principles.** Users seek optimal paths based on search tasks and contexts. Search behavior is boundedly rational—users cannot fully grasp and process all information comprehensively. They typically consider only partial factors to obtain satisfactory results. Pattern 1 applies to situations with low source credibility or content accuracy where user motivation is low, making search ease the sole behavioral determinant. Pattern 2 addresses specific search tasks where content relevance is highly valued, requiring search results to closely match needs. Users are "cognitive misers" with limited rationality, tending toward simplified heuristic search strategies that focus on task relevance rather than content accuracy.

3. **Heuristic and systematic mobile search behaviors are both distinct and interconnected.** Generally, systematic search behavior uses substantial cognitive resources for complex processing, analysis, and systematic evaluation of relevant content. Heuristic search behavior focuses on obtaining information with minimal cognitive effort. Gender-based path analysis shows female users prefer heuristic search, emphasizing search ease while ignoring source credibility, accuracy, and relevance; male users prefer systematic search, comprehensively considering all cues. However, SEM shows identical influencing factors for both behaviors—positive relationships with source credibility, search ease, and content relevance, with minimal accuracy effects. fsQCA also reveals identical sufficient and necessary conditions and triggering paths for both behaviors. Thus, heuristic and systematic behaviors are not mutually exclusive but coexist. During mobile search, users typically seek minimal effort for quick results, but when motivation and ability are high, systematic behavior occurs alongside rather than replacing heuristic behavior.

6.2 Theoretical Implications

This study reveals influencing factors and complex relationships of mobile search behavior through HSM, deepening relevant research:

1. **Introducing the classic social psychology HSM** to construct a mobile search behavior influence factor model. Considering users' elaboration levels to determine heuristic and systematic cues, this study separately examines their effects on both search behaviors, overcoming previous single-behavior-mode research limitations and more objectively revealing mobile search behavior patterns, confirming HSM's applicability in mobile search contexts.

2. **Combining SEM and fsQCA** to explore mobile search behavior mechanisms. SEM first validated linear relationships between HSM cues and mobile search behavior, then fsQCA compensated for SEM's causal analysis limitations by examining complex causal relationships from a config-

uration perspective, systematically revealing influence and configuration relationships of heuristic and systematic cues on mobile search behavior.

6.3 Practical Implications

Based on these findings, mobile search services and user experiences can be improved through:

1. **Enhancing system usability to reduce cognitive burden.** Search ease is the most critical driver—search difficulty directly affects willingness. Mobile search providers should offer convenient, effective services. For simple tasks, users focus on relevance ranking, speed, and interface friendliness, requiring optimized retrieval algorithms, faster connections, and personalized services. For difficult tasks, auxiliary query tools and diversified search methods (voice, image, QR code) should be provided to minimize search difficulty and improve ease-of-use experience.

2. **Improving information content quality and optimizing results.** Content relevance significantly affects both search behaviors—providers should improve precision and provide need-matching information. Content accuracy's non-significant effect reflects users' heuristic tendencies. However, this does not suggest accuracy is unimportant; rather, providers should leverage NLP, deep learning, and multimodal semantic understanding to accurately comprehend user needs, filter irrelevant/inaccurate information, reduce uncertainty and information overload, enabling satisfactory results with minimal effort.

Limitations include: (1) The predominantly college student sample is homogeneous, skewing results toward heuristic search—future research should diversify user groups for multi-group analysis; (2) Cross-sectional data lacks temporal analysis—future studies should expand samples and conduct longitudinal tracking; (3) Static classification of heuristic/systematic behaviors without considering individual cognitive and experiential differences—future research should refine cue classifications based on individual differences.

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Author Contributions

Chen Minghong: Research design, data collection and analysis, manuscript writing and revision.
Huang Hanhui: Data analysis, manuscript writing and revision.

Note: Figure translations are in progress. See original paper for figures.