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Mobile information search for location-based information

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This study investigated mobile searching for location-based information by carrying out two experiments in an airport. The independent variables were user context, information type, information requirement pressure, and location-based information type. Experiment 1 compared users' search performance in different user contexts while searching for different types of information. The results indicated that when users searched for location-based information, the average number of clicks decreased, the importance of the first search result increased, and free recall was better compared with non-location-based information searching. Experiment 2 further investigated the users' mobile search performance under different levels of information requirement pressure. The results indicated that users under low pressure clicked more search results compared with users under high information requirement pressure. Compared to transactional query searching, when users engaged in informational and navigational queries, the average number of clicks increased, the importance of the first search result decreased, and free recall was worse. There was no significant difference in the number of clicks when users chose the first two search results during a mobile searching process for location-based information.

1. Introduction

With the development of mobile and wireless technologies, people can access search engines anytime from any place. When users perform mobile searching, the time pressure is generally higher, environmental disturbances greater, and the limitations of the mobile device (such as screen size and input method) will restrict the users' operations.

In the mobile context, most information can be considered as location-based information. Thus, it is possible for search engines to analyze users' information queries and location to provide more suitable mobile search results accordingly. In mobile searching for location-based information, new ranking principles can be applied based on the specified user context and information type.

Many human factor specialists, psychologists, and engineers have devoted efforts to improve the user satisfaction with and the efficiency of the information searching process. However, most of these studies focused on the non-mobile context. Normally, these experiments were conducted in the lab with participants operating desktop PCs to perform the searching tasks. The results in the non-mobile context may not be applicable for the mobile context.

In this study, we investigated mobile searching for location-based information. Information searching tasks were designed to be completed in the real mobile context to experimentally evaluate the effects of location and information type. User information searching performance, such as the number of clicks, importance of the first search result, and free recall, were collected and analyzed.

2. Literature review

2.1. Features of mobile interaction

Kristoffersen and Ljungberg [1] explained that mobile devices require our physical and attentional capabilities. They indicated four important features in the mobile context: (1) Tasks external to operating the mobile computer are the most important, as opposed to tasks taking place "in the computer". (2) Users' hands are often used to manipulate physical objects, as opposed to users in the traditional office setting, where the users' hands are safely and ergonomically placed on the keyboard. (3) Users may be involved in tasks that demand a high level of visual attention, as opposed to the traditional office setting where a large degree of visual attention is usually directed at the computer. (4) Users may be highly mobile during the task, as opposed to in the office, where typing and other actions are often separated.

Similarly, Pascoe et al. [2] identified four mobile context characteristics: (1) Dynamic user configuration. The users want to collect data whenever and wherever they like. However, there will not always be chairs or desks nearby on which to set up their computing apparatus. (2) Limited attention capacity. Users need to spend as much time as possible observing to minimize the time devoted to data collection. (3) High-speed interaction. The user is

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normally a passive observer whose work is subject-driven; therefore, during some spurts of activity they need to be able to enter high volumes of data very quickly and accurately, or it may be lost forever. (4) Context dependency. The users' activities are intimately associated with their context, or the subject's context. Lumsden and Brewster [3] noted a common conflict between mobility and mobile HCI: Interacting with a mobile device, as a task, induces competition for the same limited resources required to navigate through the environment safely [4]. The study of Oulasvirta et al. [5] demonstrated the impulsive, fragmented, and drastically short-term nature of attention in mobility due to resource competition. Continuous attention to the mobile device fragmented and broke down to bursts of just 4–8 s.

Nagata et al. [6] studied the disruption of user attention and found that the disruptions in a multi-tasking setting have a critical impact on a person's attention, limiting task performance, in particular for mobile devices compared to the desktop PC. The study of Oulasvirta et al. [5] showed that attention to the mobile device had to be interrupted by glancing at the environment up to 8 times during a subtask of waiting for a Web page to be loaded.

2.2. Location-based information

Location-based information is common on the Web. Previous studies revealed that a significant portion of the queries on general search engines can be considered as location-based queries. Nearly one-fifth of Web search tasks are related to a specific place or region [7,8].

A survey [9] reports that 44% of Web users are frustrated by navigation and search engine use. Using only keywords as an index can leave the user to sort through pages of results when queries are related to physical locations and distances rather than cyberdistances. Due to the fact that most human activities occur locally around a user's location, capturing location-based information on the Web is becoming more and more important, especially in the mobile and local search environments. Kaasinen [10] studied users' need for location-based services and found that topical information, which is the kind of information that may change while the user is on the move, and guidance on how to proceed in the changed situation are important to users.

Watters and Amoudi [11] found that over 80% of the URLs tested could be assigned correct location coordinates. This means that 80% of the information on websites is location-based. For queries with a geospatial dimension, it is possible to rank search results based on location-based information.

In addition to keywords, queries could be expanded to include appropriate location-based terms as well. Several algorithms have been developed to incorporate location-based item into the ranking of search results. Yokoji et al. [12], for example, extracted addresses from the content of Web pages and found a 25% increase in search hits for region-based queries when the location plus keywords were used. Recently; more and more commercial search engines have started to provide location-based services. These services are particularly useful for mobile users.

2.3. Information pressure and time pressure

Different information requirement pressures impose different time pressures on users. Verplanken [13] found that, under time constraints, subjects scoring low in need for cognition (NFC) appear to use more heuristic (i.e., simpler) information search strategies than do high-NFC subjects. Oulasvirta et al. [5] recorded percentages of time spent attending the environment during page loading under three different instructed time pressure (ITP) statuses: hurrying, baseline, and waiting. The results reveal a decrease of three percentage points due to asking participants to hurry in a HCI task, and an increase of nine points for the waiting ITP. This provides tentative evidence that HCI tasks are lower in the goal hierarchy compared to other tasks.

2.4. Search queries

Broder [14] defined three types of information search queries: navigational queries, informational queries, and transactional queries. The purpose of the navigational query is to reach a particular site. The purpose of the informational query is to find information presented on one or more web pages. No further interaction is predicted, except reading, for these two types of information. The keywords for searching are usually vague, so that users may have to check several results to find the information they need. However, the purpose of the transactional query is to visit a site and perform some web-mediated activity. Further interaction will happen, for example, filling in some forms, selecting some menus, and accessing certain databases. For a transactional query, it is important to present the search results in a way that the user can find the target site easily. Church et al. [15] conducted a large scale study of European mobile search behavior. The results indicated informational queries accounted for 10.2% of all the queries investigated, navigational queries 29.4%, and transactional queries 60.4%. They explained that people may not conduct traditional searches for general information online using their mobile devices.

2.5. Measuring performance of information search

Past studies have found that users usually browse only the first or perhaps the second page of search results [16,17]. Jansen and Spink [18] found that Web search engine users on average viewed about eight Web documents, with more than 66% of searchers examining fewer than five documents in a given session. Users on average viewed two to three documents per query. Over 55% of Web users viewed only one result per query. Twenty percent of Web users viewed a Web document for less than a minute. These results show that the initial impression of a Web document is extremely important to the user's perception of relevance.

Using eye tracking techniques, it was found that only about one-fifth of the participants viewed the query result abstracts in the order of their ranking, and only an average of about three abstracts per result page was viewed [19]. Users looked at only the first Google result page containing the first 10 abstracts in 96% of queries. No participants went beyond the third results page. Most of them viewed the first and second results rather equally in frequency. However, they chose to click on the first result most of the time. The results indicate that for each query only the most highly ranked search results are likely to be exposed to the users.

Kamvar and Baluja [20] conducted a large scale study of US users' search patterns on Google's mobile search interface. The results showed users followed fewer than 10% of queries with at least one click on a search result. For those users who did click through, the number of clicks per query averaged 1.7. And only 8.5% of the queries had at least one "more search results" request. Their later study showed that the percentage of queries with at least one click on a search result rose to well over 50% [20]. A similar study conducted by Church et al. [15] on European mobile search behavior revealed that the percent of users who click on at least one result is just 25, compared to 56% for traditional Web searches [22]. Mobile searchers tend to focus on the first few search results, even more so than on the traditional Web searches [15].

Neerincx and Streefkerk [22] studied user's search performance using a mobile device compared to a laptop. They found distinct decreases in performance in the mobile context because of the high arousal, positive valence condition. Participants took up to 300% longer to complete information search tasks and their mental workload increased by 70%. They also found that task performance with the mobile device resulted in a lower valence score than with the laptop. Users experienced more negative emotions with the mobile device. Mobile searchers frequently failed to locate what they are looking for in a timely manner; vague queries continued to dominate mobile searches and few users had the patience to search long result lists on their mobile handsets [21].

3. Hypotheses

3.1. Hypothesis 1

For information searches, the average number of clicks in the mobile context is less than that in the non-mobile context. The importance of the first search result in the mobile context is greater than that in the non-mobile context. Free recall in the mobile context is worse than in the non-mobile context.

Users in the mobile context are more easily disturbed by external objects, and they cannot focus on the mobile device for a long time. The time for prefocus exploration, focus formulation, and information collection is reduced. The user must decide whether the search result is relevant as quickly as possible. Therefore, in the mobile context the users have to speed up their information search process, click the search results less, and click only the first search result; they also have poor recall.

3.2. Hypothesis 2

For information searching, the average number of clicks when searching for location-based information is less than that when searching for non-location-based information. The importance of the first search result is greater than that when searching for non-location-based information. The free recall in location-based information searches is better than that in non-location-based information searches.

Watters and Amoudi [11] found that over 80% of the URLs tested could be assigned correct location coordinates. Saracevic [23] also indicated that the intention in relevance expression is usually directed toward the context, such as in location-based information. When searching for location-based information, users tend to click the search results less, and especially click only the first search result; they also have better free recall.

3.3. Hypothesis 3

For mobile information searching, the average number of clicks under a high pressure information requirement is less than that under a low pressure information requirement. The importance of the first search result under a high pressure information requirement is greater than that under a low pressure information requirement. Free recall under a high pressure information requirement is worse than that under a low pressure information requirement

Different information requirement pressures mean different time pressures. The user may accelerate processing, they may be less selective in evaluating information, or they may choose different search and processing strategies in response to time constraints [13]. The user under a high pressure information requirement would be affected by high time pressure and they would have poor performance during the mobile searching process.

3.4. Hypothesis 4

For mobile information searching, the average number of clicks when making an informational or navigational query is greater than that when making a transactional query. The importance of the first search result when making an informational or navigational query is less than that when making a transactional query. Free recall when making an informational or navigational query is worse than when making a transactional query.

For informational and navigational queries, less interaction is predicted, except reading and clicking. For a transactional query, further interaction will occur; this interaction constitutes the transaction, and defines the query as transactional. The greater number of interactions increases the user's immersion. Thus the decision-maker will be less likely to consider information supporting an alternative choice.

4. Methodology

Two experiments were designed in this study to investigate the effects of four independent variables in user information search performance (Fig. 1). Experiment 1 was designed to test Hypotheses 1 and 2. The independent variables were the user's context (mobile context and non-mobile context) and information type (location-based information and non-location-based information). Experiment 2 was designed to test Hypotheses 3 and 4. The independent variables were the information requirement pressure (low and high) and the type of location-based information (informational, navigational query or transactional query). The 2×2 factorial design was used for both experiments.

4.1. Apparatus

An OQO Model 01 mobile computer was used for the information searching tasks. The screen size was five inches, with 800×480 screen resolution. The search results page layout was similar to Google (Fig. 2). There were 10 results per page. All of the results were relevant to the task.

4.2. Procedure

All participants filled out a general information questionnaire concerning their personal characteristics, including age, education level, computer experience, mobile device experience, and search experience. Each participant was given instructions on searching for information with a mobile device and then asked to perform the

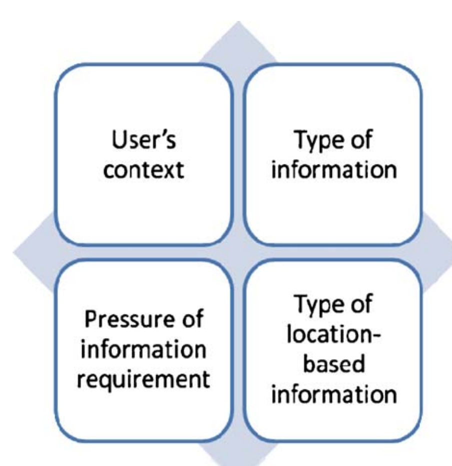

Fig. 1. Factors proposed that may influence the mobile information search.

Fig. 2. The layout of the experiment website.

tasks. Upon task completion each participant took a free recall test about the information that they had obtained from the information search tasks. Experiments 1 and 2 followed the same procedure (Fig. 3).

4.3. Experiment 1

4.3.1. Participants

Forty-eight volunteer participants were equally assigned to two groups. The participants in group 1 were passengers at the Chengdu International Airport leaving for Beijing in about 1 h. There are about 20 flights from Chengdu to Beijing every day. The passengers' ages ranged from 22 to 37 years (mean = 29.08, SD = 3.94). Twenty of them had experience in using mobile devices to connect to the Internet. All of them had experience in using computers and search engines. The participants in group 2 were people planning to go to Beijing in the near future. Their ages ranged from 19 to 43 years (mean = 28.29, SD = 6.37). Twenty of them had experience in using mobile devices to connect to the Internet. All of them had experience using computers and search engines.

4.3.2. Tasks

The entire experiment was conducted in the real context. The participants in group 1 finished the information search tasks in the airport lounge, while the participants in group 2 conducted the searches in their office or home in the non-mobile context. Eight information search tasks were designed, including four location-based information search tasks related to Beijing and four non-location-based information search tasks (Table 1). The sequences

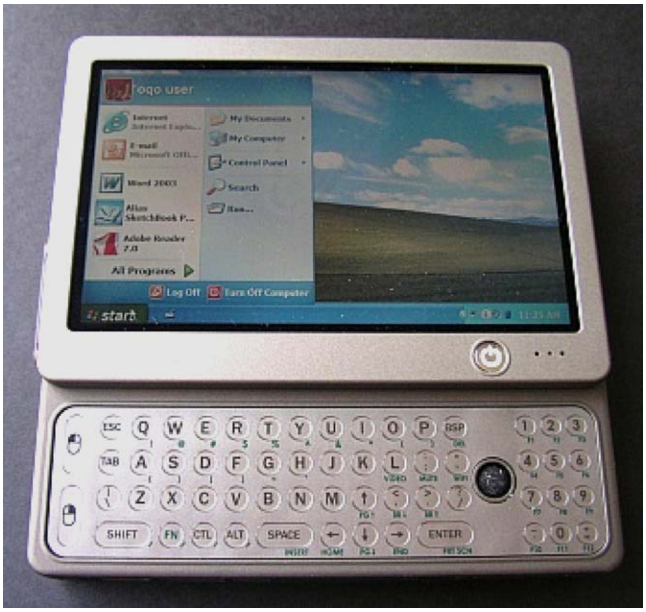

Fig. 3. The apparatus.

of the tasks were as follows: Sequence 1 was tasks 1, 2, 3, 4, 5, 6, 7, and 8; Sequence 2 included tasks 2, 3, 4, 1, 6, 7, 8, and 5; Sequence 3 was comprised of tasks 3, 4, 1, 2, 7, 8, 5, and 6; Sequence 4 was tasks 4, 1, 2, 3, 8, 5, 6, and 7; Sequence 5 was tasks 5, 6, 7, 8, 1, 2, 3, and 4; Sequence 6 was tasks 6, 7, 8, 5, 2, 3, 4, and 1; Sequence 7 was tasks 7, 8, 5, 6, 3, 4, 1, and 2; and sequence 8 was tasks 8, 5, 6, 7, 4, 1, 2, and 3.

4.4. Experiment 2

4.4.1. Participants

Forty-eight volunteer participants were equally assigned to two groups. The participants in group 1 were passengers at Chengdu International Airport leaving for Beijing in about 1 h. The passengers' ages ranged from 19 to 38 years (mean = 25.75, SD = 5.64). All of them had experience in using computers and search engines. The participants in group 2 were recruited from one hotel near Chengdu International Airport. They were scheduled fly to Beijing the next day. Their ages ranged from 24 to 42 years (mean = 29.67, SD = 6.40). Nine of them had experience in using mobile devices to connect to the Internet. All of them had experience in using computers and search engines.

Table 1
Task descriptions for Experiment 1.

Information type	Description of tasks
Location-based information	Task 1: Searching for Beijing weather forecast reports
	Task 2: Searching for information on special foods in Beijing
	Task 3: Searching for information on one-day tours in Beijing
	Task 4: Searching for Fuwa shopping information in Beijing
Non-location-based information	Task 5: Searching for information on Hollywood movies in 2006
	Task 6: Searching for personal information on Yao Ming
	Task 7: Searching for Spring Festival history and story
	Task 8: Searching for information on the Beijing Olympic Games

Table 2
Task descriptions for Experiment 2.

Type of location-based information	Description of tasks
Informational and navigational query	Task 1: Searching for information on museums in Beijing
	Task 2: Searching for information on special foods in Beijing
	Task 3: Searching for Sichuan Food restaurant information in Beijing
Transactional query	Task 4: Searching and booking a flight ticket from Beijing to Chengdu
	Task 5: Searching and booking a hotel room in Beijing
	Task 6: Searching and booking a ticket for a vocal concert in Beijing

4.4.2. Tasks

Six location-based information search tasks were designed, including three informational and navigational queries and three transactional queries (Table 2). All tasks were related to Beijing. The entire experiment was conducted in the mobile context. The participants in group 1 finished the information search tasks in the airport lounge. They were under high information requirement pressure because they would be boarding 1 h later. The participants in group 2 finished the information searching tasks in the coffee or tea shop in the hotel. They were under low information requirement pressure because they were scheduled to go to Beijing the next day. The task sequences were as follows: Sequence 1 was tasks 1, 2, 3, 4, 5, and 6; Sequence 2 was tasks 2, 3, 1, 5, 6, and 4; Sequence 3 was tasks 3, 1, 2, 6, 4, and 5; Sequence 4 was tasks 4, 5, 6, 1, 2, and 3; Sequence 5 was tasks 5, 6, 4, 2, 3, and 1 and sequence 6 was tasks 6, 4, 5, 3, 1, and 2.

4.5. Dependent variables

The number of clicks was recorded by the computer. For free recall, the participants spoke to an audio recorder to record their answers. The full free recall score for Experiment 1 was 40 points. The full free recall score for Experiment 2 was 30 points.

5. Results and discussion

The intention of Hypothesis 1 was to examine how the user's context might affect the user's information searching performance. No significant differences in the average number of clicks, importance of the first search result, or free recall were found (Table 3).

The intention of Hypothesis 2 was to examine how the information type might affect the user's information searching performance. Significant differences in the average number of clicks ($F = 42.20$, $p < 0.001$), importance of the first search result ($F = 11.04$, $p = 0.002$), and free recall ($F = 10.48$, $p = 0.002$) were found (Table 4).

The location where a user would go or where user activity was stimulated during the information search process was noticed. According to Allport et al.'s research [24], when the physical nature of a stimulus uniquely defines the nature of the cognitive processing required by that stimulus, switching to that task is more rapid than if the stimulus signals ambiguously. Users can then focus on the location-based information and find what they want as soon as possible. Wickens and Hollands [25] also pointed out that factors that increase the discriminability of items would help performance in a running memory task. One method is to use separate and unique spatial locations.

Table 3
Data for testing Hypothesis 1.

	Mobile context		Non-mobile context		F	p
	Mean	SD	Mean	SD		
Number of clicks						
The first result	0.67	0.24	0.67	0.26	$Z=-0.15$	0.883
The first two results	0.96	0.39	0.95	0.40	$Z=0.48$	0.629
The first three results	1.35	0.40	1.26	0.48	$Z=1.22$	0.221
The first four results	1.43	0.42	1.34	0.51	$Z=1.28$	0.202
The first five results	1.50	0.46	1.48	0.56	$Z=0.87$	0.385
The first 10 results	1.75	0.54	1.90	0.80	0.10	0.758
Average number of clicks	1.75	0.54	1.90	0.80	0.10	0.758
Importance of the first search result	0.46	0.21	0.42	0.19	0.78	0.383
Free recall	12.21	4.36	12.66	5.34	0.20	0.654

Table 4
Data for testing Hypothesis 2.

	Location-based information		Non-location-based information		F	p
	Mean	SD	Mean	SD		
Number of clicks						
The first result	0.68	0.27	0.66	0.22	$Z=0.35$	0.724
The first two results	0.96	0.35	0.96	0.44	$Z=0.33$	0.740
The first three results	1.23	0.36	1.38	0.51	$Z=1.95$	0.051
The first four results	1.29	0.40	1.47	0.52	$Z=2.22$	0.026[a]
The first five results	1.35	0.41	1.63	0.56	$Z=3.21$	0.001[a]
The first 10 results	1.55	0.55	2.10	0.70	42.20	0.000[a]
Average number of clicks	1.55	0.55	2.10	0.70	42.20	0.000[a]
Importance of the first search result	0.51	0.21	0.37	0.16	11.04	0.002[a]
Free recall	13.90	4.73	10.98	4.57	10.48	0.002[*]

[a] $p < 0.05$.

The intention of Hypothesis 3 was to examine how the information pressure requirement might affect a user's mobile search performance. A significant difference in the average number of clicks ($Z = -2.27$, $p = 0.023$) was found. There were no significant differences in the importance of the first search result or free recall (Table 5).

An information search process is a decision-making process. An individual may accelerate processing, possibly by being less selective in evaluating information or by choosing different search and processing strategies in response to time constraints [13]. Wright [26] found that under time pressure, decision-making performance deteriorated when more rather than less information was provided. The time pressure can also reduce the spatial area of the attention spotlight; the objects of greatest subjective importance remain unaffected or perhaps enhanced, but those of lower priority are filtered [27]. When users are under time pressure with a high pressure information requirement, they click the search results in the front rank only and filter out the others. In Experiment 2 the participants did click the search results less under a high pressure information requirement.

The intention of Hypothesis 4 was to examine how the location-based information type might affect a user's mobile search performance. Significant differences in the average number of clicks ($Z = 4.11$, $p < 0.001$), importance of the first search result ($F = 8.19$, $p = 0.009$), and free recall ($F = 40.02$, $p < 0.001$) were found (Table 6).

According to Woods et al.'s research [28], stress will initially narrow the set of cues processed to those that are perceived to be

Table 5
Data for testing Hypothesis 3.

	High pressure of information requirement		Low pressure of information requirement		F	p
	Mean	SD	Mean	SD		
Number of clicks						
The first result	0.50	0.35	0.62	0.27	$Z=-1.22$	0.224
The first two results	0.79	0.35	1.03	0.47	$Z=-1.57$	0.117
The first three results	1.00	0.39	1.34	0.59	$Z=-2.22$	0.027[a]
The first four results	1.10	0.39	1.49	0.61	$Z=-2.41$	0.016[a]
The first five results	1.24	0.42	1.58	0.73	$Z=-1.66$	0.097
The first 10 results	1.54	0.63	2.32	1.17	$Z=-2.27$	0.023[a]
Average number of clicks	1.54	0.63	2.32	1.17	$Z=-2.27$	0.023[a]
Importance of the first search result	0.37	0.28	0.29	0.16	2.49	0.129
Free recall	8.26	3.19	6.94	2.79	2.44	0.132

[a] $p < 0.05$.

Table 6
Data for testing Hypothesis 4.

	Informational and navigational query		Transactional query		F	p
	Mean	SD	Mean	SD		
Number of clicks						
The first result	0.60	0.37	0.53	0.26	$Z=1.08$	0.281
The first two results	1.01	0.53	0.81	0.26	$Z=1.11$	0.268
The first three results	1.40	0.60	0.94	0.31	$Z=2.73$	0.006[a]
The first four results	1.53	0.58	1.06	0.38	$Z=3.29$	0.001[a]
The first five results	1.71	0.63	1.11	0.44	$Z=3.79$	0.000[a]
The first 10 results	2.44	0.98	1.42	0.76	$Z=4.11$	0.000[a]
Average number of clicks	2.44	0.98	1.42	0.76	$Z=4.11$	0.000[a]
Importance of the first search result	0.24	0.16	0.42	0.25	8.19	0.009[a]
Free recall	5.87	2.38	9.32	2.64	40.02	0.000[a]

[a] $p < 0.05$.

most important. Stress will enhance the confirmation bias, causing the decision-maker to be even less likely to consider information that might support an alternative choice.

This study found that user performance in mobile searching was different from desktop searching. The participants viewed only 1.86 search results per query on average, and the click ratio for the first search result was 0.40. Compared to the past studies using a desktop PC [16,17], users clicked fewer search results per query in this study. The user's context influences the user's mobile search performance. Normally, in mobile searching there are many kinds of disturbances from the environment. The time the user has to find the exact required information is limited. Overstimulation and time pressure will accelerate a user's decision-making process; therefore, users cannot pay full attention to the search tasks.

6. Conclusion

Mobile search engines can help users get the exact information required from billions of data anytime, anywhere. Users' mobile search performance is influenced by the mobile device and their context. It is not convenient to input or change the search keywords on a mobile device. Some accessorial functions can be developed to solve this problem. Furthermore, the order of the search results can be customized according to the users' context and the information types in mobile searching. Also, the search engine should pay more attention to the first two results for mobile information searchers.

The results of this study can be summarized as follows:

- Information type was found to be effective in user performance during the information search process. When users searched for location-based information, they clicked the search results less, the importance of the first search result was greater, and they had better recall than when searching for non-location-based information.
- Information requirement pressure was found to be effective in the number of clicks during the mobile search process. Users under low information requirement pressure clicked the search results more than users under high pressure information requirement.
- Location-based information type was found to affect user behavior during the mobile search process. When users made a transactional query, they clicked the search results less, the importance of the first search result was greater, and they had better free recall than when making informational and navigational queries.
- The first two search results were found to be very important to good search efficiency and good user satisfaction.

References

[1] S. Kristoffersen, F. Ljungberg, "Making Place" to make IT work: empirical explorations of HCI for mobile CSCW, in: Paper Presented at the International ACM SIGGROUP Conference on Supporting Group Work, 1999.
[2] J. Pascoe, N. Ryan, D. Morse, Using while moving: HCI issues in fieldwork environment, ACM Transactions on Computer-Human Interaction 7 (3) (2000) 417–437.
[3] J. Lumsden, S. Brewster, A paradigm shift: alternative interaction techniques for use with mobile & wearable devices, in: Proceedings of CASCON'03, 2003.
[4] N. Sawhney, C. Schmandt, Nomadic radio: speech & audio interaction for contextual messaging in nomadic environments, ACM TOCHI 7 3 (2000) 353–383.
[5] A. Oulasvirta, S. Tamminen, V. Roto, J. Kuorelahti, Interaction in 4-Second Bursts: the fragmented nature of attentional resources in mobile HCI, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2005, pp. 919–928.
[6] S. Nagata, M. Neerincx, H. Oostendorp, Scenario based design: concepts for a mobile personal service environment, in: Paper Presented at the 10th International Conference on Human-Computer Interaction, Heraklion, Crete, Crete University Press, 2003.
[7] M. Sanderson, J. Kohler, Analyzing geographic queries, in: Proceedings of the SIGIR 2004 Workshop on Geographic Information Retrieval, Sheffield, UK, 2004.
[8] S. Asadi, Searching the World Wide Web for local services and facilities: a review on the patterns of location-based queries, in: WAIM'05, Hong Zhou, China, 2005.
[9] Search Engine Watch, Survey Reveals Search Habits, http://searchenginewatch.com/2162681, retrieved at May 8, 2009.
[10] E. Kaasinen, User needs for location-aware mobile services, Personal and Ubiquitous Computing 7 (1) (2003) 70–79.
[11] C. Watters, G. Amoudi, GeoSearcher: Location-based ranking of search engine results, Journal of the American Society for Information and Technology 54 (2) (2003) 140–151.
[12] S. Yokaji, K. Takahashi, N. Miura, Konono Search: a location based search engine, in: Proceedings of the Tenth International World Wide Web Conference, Hong Kong, (2001), p. 1146.
[13] B. Verplanken, Need for cognition and external information search: responses to time pressure during decision making, Journal of Research in Personality 27 (1993) 238–252.
[14] A. Broder, A taxonomy of web search, SIGIR Forum 36 (2) (2002) 3–10.
[15] K. Church, B. Smyth, K. Bradley, P. Cotter, A large scale study of European mobile search behaviour, in: Proceedings of MobileHCI'08, 2008, pp. 13–22.
[16] C. Silverstein, M. Henzinger, H. Marais, M. Moricz, Analysis of a very large Web search engine query log, ACM SIGIR Forum 33 (1) (1999).
[17] A. Spink, S. Ozmutlu, H.C. Ozmutlu, B.J. Jansen, US versus European Web searching trends, SIGIR Forum (Fall) (2002).
[18] B.J. Jansen, A. Spink, An analysis of web information seeking and use: documents retrieved versus documents viewed, in: Paper Presented at the 4th International Conference on Internet Computing, Las Vegas, Nevada, 2003.
[19] L. Lorigo, B. Pan, H. Hembrooke, T. Joachims, L. Granka, G. Gay, The influence of task and gender on search and evaluation behavior using Google, Information Processing and Management 42 (4) (2005) 1123–1131.
[20] M. Kamvar, S. Baluja, A large scale study of wireless search behavior: Google mobile search, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2006, pp. 701–709.
[21] B. Smyth, E. Balfe, O. Boydell, K. Bradley, P. Briggs, M. Coyle, J. Freyne, A live-user evaluation of collaborative web search, in: Proceedings of the 19th International Joint Conference on Artificial Intelligence (IJCAI'05), Edinburgh, Scotland, 2005.
[22] M.A. Neerincx, J.W. Streefkerk, Interacting in desktop and mobile context: emotion, trust and task performance, in: Paper Presented at the Proceedings of the First European Symposium on Ambient Intelligence (EUSAI), Eindhoven, The Netherlands, 2003.
[23] T. Saracevic, Relevance reconsidered'96, in: P. Ingwersen, N.O. Pors (Eds.), Information Science: Integration in Perspective, Royal School of Library and Information Science, Copenhagen, Denmark, 1996, pp. 201–218.

[24] D.A. Allport, E.A. Styles, S. Hsieh, Shifting intentional set: exploring the dynamic control of tasks, in: C. Umilta, M. Moscovitch (Eds.), Attention and Performance XV, MIT Press, Cambridge, MA, 1994, pp. 421–452.
[25] C.D. Wickens, J.G. Hollands, Engineering Psychology and Human Performance, 3rd ed., Prentice-Hall Inc, Upper Saddle River, NJ, 2000.
[26] P. Wright, The harassed decision maker: time pressures, distractions, and the use of evidence, Journal of Applied Psychology 59 (1974) 555–561.
[27] S.J. Bacon, Arousal and the range of cue utilization, Journal of Experimental Psychology 102 (1974) 81–87.
[28] D.D. Woods, L.J. Johannesen, R.I. Cook, N.B. Sarter, Behind human error: Cognitive systems, computers, and hindsight (State of the Art Report CSERIAC 94-01), Wright-Patterson AFB, CSERIAC Program Office, Dayton, OH, 1994.

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