Influence of spatial ability in navigation: using look-ahead breadcrumbs on The Web

Ishtiaq Ahmed and James Blustein*

Faculty of Computer Science
Dalhousie University
Halifax, NS, Canada
Fax: +1 902–492–1517
E-mail: ishtiaq@cs.dal.ca
E-mail: jamie@cs.dal.ca
*Corresponding author

Abstract: Breadcrumbs are a type of navigational aid intended to help users of large well-structured websites by providing information about the location of the current webpage within the site's structure. The phenomenon of user disorientation (feeling lost) when using hypertext in abstract information-rich environments such as WWW-based directories is well known. Earlier experiments have been unable to explain why visual mediators that improve navigation for people with lower Spatial Ability (SA) seems to have the opposite effect for other people.

Results from our experiment indicate that spatial ability influenced navigation efficiency in navigating a vast hierarchical website. Users in the higher SA group were more efficient and had a different (marginally significant) preference for website's breadcrumbs over the browser's Back button. There was no significant difference for time or accuracy between the two groups. Those results suggest that users with lower SA use different approaches to navigating websites than others.

Keywords: hypertext navigation; spatial ability; information space; information visualisation; breadcrumbs.

Reference to this paper should be made as follows: Ahmed, I. and Blustein, J. (2006) 'Influence of spatial ability in navigation: using look-ahead breadcrumbs on The Web', *Int. J. Web Based Communities*, Vol. 2, No. 2, pp.183–196.

Biographical notes: Mr. Ishtiaq Ahmed is a Masters of Computer Science student.

Professor James Blustein is an Assistant Professor of Computer Science at Dalhousie University, Canada. Professor Blustein's primary research interest is in hypertext interfaces to improve access to, and use of, information.

1 Introduction

Spatial ability is the ability to perceive spatial patterns or to maintain orientation with respect to objects in space (Ekstrom *et al*., 1976). It is the cognition of spatial properties of the world such as location, size, distance, direction, shape, movement, *etc*. In the context of navigation, it is the perceptual ability on the information space based on user's previously acquired knowledge, information processing capability and motor capability on spatial properties in the real world. Spatial ability is often cited as a good predictor of individual's performance in human-computer interactions (Egan, 1988; Stanney and Salvendy, 1995). The influence is more eminent in the act of browsing or navigation in an interaction space, if it has somewhat spatial layout inherent in it (Benyon and Murray, 1993; Dahlbäck *et al*., 1996).

Identifying the model in which people conceptualise the whole interaction environment and the extent of spatiality in this model is yet to be resolved clearly. There is still a need to forecast the browsing patterns of people with varying spatial abilities. The basic premise behind the metaphor is that finding information in a significantly large information space is psychologically similar to navigating in real-world space and, hence, promoting the existence of a mental architecture that conceptualise the information space in a spatial manner, may increase the affectiveness, efficiency and enjoyment of navigation. It is believed that navigation performance of people with low spatial ability can be improved by providing them with a visual tool that assists in grasping the layout of the space (Robertson, 1997; Vicente and Williges, 1988). Benyon and Murray (1993) and Höök and Dahlbäck (1997) conducted studies that clearly showed that people with high spatial ability can visualise the organisation of information better than people with low ability. Stanney and Salvendy (1995), found that a visual tool for hierarchical representation of information is an effective means by which to accommodate individuals with low spatial abilities in information-seeking tasks. But, another work by Chen (2000) revealed that it is not the spatial ability, rather, the experience with the system that matters effectively in the performance of navigation in information space. Another interesting study (Allen, 1998) reveals that spatial organisation of information helps the low-ability people with their way finding but, in some cases, negatively affects the high spatial-ability people. Dillon and Vaughan (1997) were somewhat sceptic in their landmark article on information shape, on the rationale of looking at the information systems as a metaphor of real-world space. Instead, Dillon suggested the idea of Information Shape, which, in his view, was more suitable to express the users' actual mental and physical tasks in information seeking (Dillon and Vaughan, 1997; Dillon, 1995). However, the contraposition of results and divergence in opinion call for more efforts like ours on this topic.

2 Navigation in information space

Navigation is the process of moving from one location to another and knowing the relative position in order to reach the desired destination in a spatial environment. It includes understanding, partitioning an environment, exploring it and finding the right way to the end from starting point (Benyon, 2001). In order to explain information space, Benyon (2001) introduced the idea of activity space. *Activity space* is the physical spatial environment in which people perform a certain activity. Information space is the structured collection of information consisting of various information artefacts and signs from where subjects seek information for their activity space. According to results from the study by Dieberger (1997), visualising an information space is necessary for effective navigation. That is why people often impose metaphors to information space to give it a visual structure. Apart from the large body of information contained in it, an information space can be envisioned as a set of nodes, each of which is an information unit or sign (van Dyke Parunak, 1989). The topology of these nodes makes it resemble a space that can be traversed. The complete structure takes a shape like a city or town where the way-finder is not forced to take any single path to reach a destination. In this sense, hypermedia is the most notorious example of an information space. Besides, newspapers, television and even a single autonomous computer or paper document can be treated as an information space. The evolution of the World Wide Web over the past several years has been astounding. Due to its huge information content and complexity in navigation, salience and structure make it the most complex information space for information users. Navigation in information space, thus, can be defined as the process where user moves through the virtual information network by following links from node to node and senses position in the network relative to the destination node. Navigation and way finding are used as similar terms in many works when it comes in the context of electronic information space (Dahlbäck and Lonqvist, 2000). Based on the size, orientation and structure, the navigation mechanism varies from one information space to another. There are numerous definitions for navigation in information space and Dahlbäck and Lonqvist (2000) concluded it as a task rather synonymous to information retrieval.

3 Spatial ability

Analysing and understanding spatial ability is a complex affair in psychology. Every task that presents figural stimuli does not require spatial ability to exploit by the individual. Nor does the absence of a figural stimulus mean that there is no spatial processing (Lohman and Kyllonen, 1983). *Spatial ability* or thinking, in general, requires several psychological attributes, such as ability to encode information, remember, transform and differentiate spatial objects (Lohman and Kyllonen, 1983). Kritchvesky's posits on spatial ability are quite acceptable to the community (Caplan and Romans, 1998). According to him, there are five broad categories of spatial functions, which are perception, memory, attention, mental operations and construction. The functions, all together, contain nine basic spatial skills. These are object localisation, line orientation detection, spatial synthesis, short-term spatial memory, long-term spatial memory, attention to left hemispace, attention to right hemispace, mental rotation and spatial construction. Other spatial properties proposed by various authors include visual scanning, face recognition, topographical orientation, and identification of incomplete figures and detection of hidden figures. Much research has been conducted to devise appropriate psychological tests to measure these abilities. Ekstrom *et al*. (1976), Lohman and Kyllonen (1983) and Caplan and Roman's (1998) compilations are some of these to name few. An expansive discussion on these tests is beyond the scope of this study.

4 How people create mental models during navigation

The spatial ability of an individual comes to play when the user performs the task of navigation in information space. For instance, authors of an information space possess a semantic structure of information pieces that primarily reside in their minds. The virtual space that is created by unifying these models of one or more authors is not more than a transient representation of the whole information. A reader or information seeker, when he/she comes to interact with the intermediate representation, tries to develop another mental model based on what is seen or found through the navigation. It is believed that if the information nodes are related spatially in some extent, both the authors and readers develop a space out of these nodes where they start navigating, unconsciously, during developing or traversing the virtual model (*e.g.*, a WWW site). The shape of this space depends on the individual's various cognitive abilities where spatial ability is, presumably, the principal component (Benyon and Murray, 1993).

Based on the model, a user tries to predict the hidden surfaces or parts of the space. Dillon (1991), in his article on readers' model on academic articles, showed results that support the existence of such a predictive model in each reader's mind during interaction with paper or digital journal articles. The accuracy of this prediction depends on how the reader designs the structure based on his/her experiences and various cognitive abilities. Our principal focus is on finding the influence of the user's spatial ability in creating such a model and how information can be presented to the user so that the user can predict the original structure of information better and, essentially, enjoy effective navigation.

5 Navigation and spatial organisation of information

Background studies, such as those by Allen (1998), show that spatial organisation of information visualisation helps in learning and memory. As short-term memory plays a key role in navigation sessions (Hewett, 1998), spatial organisation of information, eventually, results in better navigation in information space. Again, long-term memory encapsulates experiences and habits in the human brain (Tulving, 1983; Coone and Fisher, 1998). Chen (2000) identified experience with the system as the main factor for lost-less navigation. Taken as a whole, spatial organisation of information has received much focus on finding the exact relation between spatial ability and conceptualisation of information space. Stanney and Salvendy (1995) found that visual mediators, such as 2D and 3D organisations of information, remove the discrimination of mental models between people with low and people with high spatial ability. Similar results were found where Allen (1998) showed that it was not the people with high spatial ability, but rather those with low spatial ability who got benefited from the spatial representation of information. One of Allen's interesting results was where high spatial people's performance degraded due to the presence of spatial layout of information. Höök and Dahlbäck (1997) also studied that visual momentum in information space helps with low spatial people. It is still not established firmly how high spatial people are affected exactly by the spatial representation of information.

In the next section, we discuss the framework that is designed to find answers to these questions. We choose the World Wide Web as the information space for navigation because of its complexity and enormity.

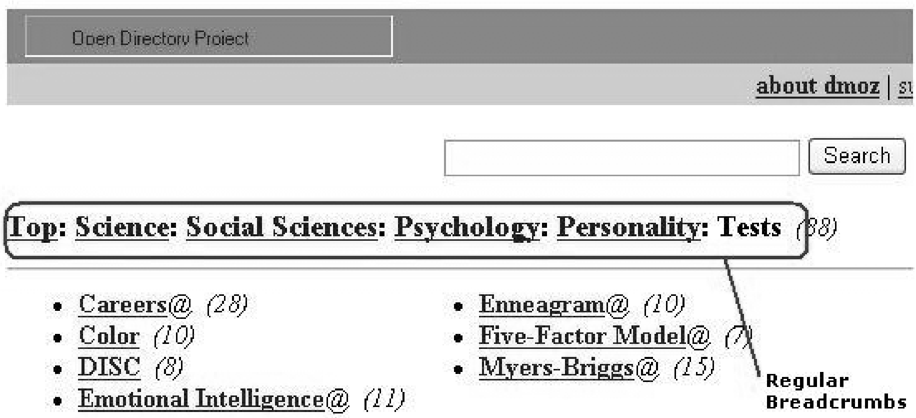
6 Research framework

The purpose of this research is to gain a better understanding of how a special navigational tool called Breadcrumbs in the World Wide Web (WWW) sites helps people in their information seeking and keep them away from the state of being lost (Smith, 1996). *Breadcrumbs*, in general, are a list of hyperlinks that "convey information to the user (about the site structure or the path they have taken), and to also give users a way to select links from the breadcrumbs (in order to go 'up' in the site hierarchy or to re-trace their steps)" (Instone, 2002). Breadcrumbs have evolved as a major navigational tool of the WWW, but there has been little research regarding their "precise concepts and terminology in order to effectively use breadcrumbs in different situations" (Instone, 2002).

Instone (2002) distinguished three types of breadcrumbs: location, path and attribute breadcrumbs. Location breadcrumbs show readers where the current web page is in the hierarchy of the current website. As such, they are rather like route markers on a highway, which are consistent with author's model. Path breadcrumbs show readers the sequence of web pages that they visited at the current site to 'arrive at' the current web page. Sometimes, a page can contain several paths of breadcrumbs about other pages that share some common attributes with the current page. These are attribute breadcrumbs. From the definition, it is clear that location breadcrumbs give user an idea of where exactly they reside in the site hierarchy. This helps in better understanding the structure of that particular information space. Throughout the rest of this framework, the term 'regular breadcrumbs' *(RBC)* will generally mean location breadcrumbs, if not specifically indicated.

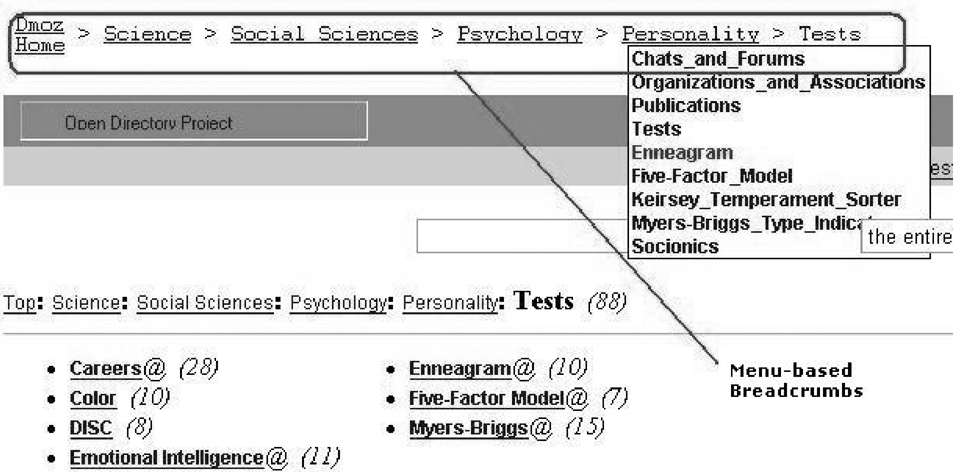
Many examples of regular location breadcrumbs can be found in websites. Figure 1 shows an example of regular breadcrumbs.

Figure 1 An example of regular breadcrumbs



Hochheiser *et al.* (1999) investigated the performance benefits of simultaneous over sequential menus and found that sequential menus are better suited for information query where some kind of hierarchy exists (Hochheiser *et al.*, 1999). In another study by Zaphiris *et al.* (2002), in-place expandable menus in web environment present a hierarchy of choice to users and reduce backtracking and getting lost. The experimental breadcrumbs *(EBC)*, that we developed, provide both simultaneous and sequential features for a website, which is an ideal combination for such navigation tasks. The experimental breadcrumbs look like regular breadcrumbs at first; but there is a menu associated with each of the breadcrumbs and it pops up when the user moves the mouse over that specific breadcrumb item. The menu contains all the links that are one level deeper in site hierarchy of that particular item. Figure 2 shows an instance of experimental breadcrumbs.

Figure 2 An example of experimental breadcrumbs



Neerincx and Lindenberg (1999) abridged three types of spatial navigation support that help people in way finding in large information space. These are landmarks, history map and navigation assistant. Landmarks are the navigation cues that help users in recognising their situation in the search space. A history map keeps a trail of users, navigation activities. A navigation assistant has the knowledge of the domain and is able to dynamically provide advice to the individual user by analysing various individualistic factors like interest, browse history, profession, education and age.

In experimental breadcrumbs, the breadcrumb trail shows the history of the user's navigation activities. The pop-up menu is dynamic in the sense that it always directs users where else they can go from that specific breadcrumb item. The definition of experimental breadcrumbs, itself, contains the landmark feature of an ideal navigation tool. As the links in the menus are exactly one level down the site hierarchy, it gives users the awareness regarding their situation during navigation. Allen's (1998) work on spatial information presentation clearly shows the effectiveness of 2D spatial layout of information for people with low spatial ability in their navigation in information space. The 2D representation style of the experimental breadcrumbs, hence, reduces the limitation of regular linear breadcrumbs that might be experienced by people with low spatial ability.

7 Experiment

To investigate the utility of the research framework, we designed an interactive experiment using human participants. Participants signed consent forms stating that they were voluntarily participating in the experiment. They completed a preliminary questionnaire, which included information, such as age, sex, education and familiarity with The Web. Before performing navigation tasks, each participant took part in two paper/pencil-based tests to assess spatial ability. The navigation part of the study used two conditions of task set. Each task was to reach a destination page, as the question demanded, in a large hierarchical website through navigation. Each condition had four such tasks with alternating sequence of presence of regular and experimental breadcrumbs in a cross-over design. The first two tasks were specified as practice session and the last two as the test session. The participants were assigned to either of the two conditions in predetermined sequence so that the population for each condition remained balanced. After completion of the task sets, participant was requested to fill out a post-experimental questionnaire. The post-experimental questionnaire asked participants to rate initial instruction; use of breadcrumbs; and aspects of the website, such as format, ease of use, ease of navigation, speed of download, and satisfaction on a five-point Likert scale.

7.1 Website and data extraction

The study required a large hierarchical website where a meaningful hierarchy exists. Open Directory Project site (http://www.dmoz.org) is such a site. It contains more than four million site references having around 64 739 editors and over 590 000 categories. These statistics were found from the downloaded copy of the site for the experiment. The whole site was downloaded using HTTrack, a website copier (http://www.httrack.com) and ‘Mutator’, a web crawler developed for this study. The web pages for this experiment are permitted for use according to the free-use licence of the Open Directory Project. Once copied, we reproduced a different version of the whole Open Directory Project site in which experimental breadcrumbs were inserted in each page. Both the downloaded and modified sites were hosted at the Unix server ‘Flame’ of Faculty of Computer Science, Dalhousie University. Two subdomains were created under the Faculty of Computer Science website to access the sites. The site with regular breadcrumbs was hosted under the ‘dmoz’ subdomain of the faculty website (http://dmoz.cs.dal.ca). The other site with experimental breadcrumbs was accessed using the ‘mdmoz’ subdomain of the same parent website (http://mdmoz.cs.dal.ca).

7.2 Participants

The 26 unpaid volunteer participants of the experiment were graduate ($n = 16$) and undergraduate ($n = 10$) students of Dalhousie University. Sixteen participants were from the Computer Science discipline, seven were from the Faculty of Science and the rest were from other disciplines. The spread of age range was from < 20 ($n = 1$) to 41–50 ($n = 1$) with the age range 21–25 years having the highest frequency (*i.e.*, 12). There were 19 male and seven female participants and all of them were familiar with the WWW environment and spend an average of six to ten hours on the internet each day. One participant faced a problem in understanding the language of the website and hence, the result from that participant was excluded from the final analysis. Recruitment of participants consisted of in-class recruitment with permission from instructors, in-person and e-mail message to the students' group-mail.

7.3 Spatial ability tests

In this study, spatial visualisation ability was assessed using the paper/pencil-based paper folding test (VZ-2) and surface development test (VZ-3) from the Kit of Factor-Referenced Cognitive Tests (Ekstrom *et al.*, 1976).

7.4 Data acquisition

For data acquisition purposes, the customised usability testing service, Uzilla,[1] was used in the study. Uzilla is an instrumented web browser that logs user interaction details like clicks, mouse downs, mouse overs and scrolling with the internet-based systems into its integrated, analysis and aggregation data collection server (Edmonds, 2003).

7.5 Independent variable

Spatial ability was the independent variable that has been focused on in this study. Spatial ability score for each participant was the sum of scores on the VZ-2 and VZ-3 tests. Answers were corrected for guessing following the equation described in the Manual for the Kit of Factor-Referenced Cognitive Tests (Ekstrom *et al.*, 1976). Skewness and kurtosis of the distribution were calculated using statistical functions available in Microsoft Excel 2003. The skewness of the distribution was 0.18. The value, being close to zero, meant that the distribution was not skewed and did not have any heavy left or right tail. The kurtosis score was –0.83. According to the analysis, an ideal normal distribution should have a kurtosis score equal to zero. The negative value indicated that the distribution was not peaked but rather was relatively flat. There were no statistics available on these tests in Kit of Factor Referenced Cognitive Tests (Ekstrom *et al.*, 1976). However, a previous compilation of this kit by French *et al.* (1963) contains statistics on these tests from two studies. The first study had 46 college students as participants. The mean score was 28.7. Another study, found in the same (French *et al.*, 1963), used 86 Army enlistees as participants. The mean score in this study was 24.1. The mean score for this study was 21.67.

Of the 26 participants, there were 13 participants for both Conditions 1 and 2. The participants were partitioned into two groups: 'low' and 'high' by the median (21.38) of the spatial ability scores. Thirteen participants above the median were placed in the high spatial ability group and 13 participants below the median were placed in the low spatial ability group. However, after classification, for Condition 1, there were seven participants in the low spatial ability group and six participants in the high spatial ability group. For Condition 2, there were six participants in the low spatial ability group and six participants in the high spatial ability group. For this condition, one participant who faced problem in understanding the language of the website, was not considered for the classification.

7.6 Dependent variables

7.6.1 Speed

Speed was calculated from the time taken (in seconds) to complete a task. A low score in this measure indicated more speed.

7.6.2 Accuracy

The accuracy or effectiveness measure was quite straightforward. Accuracy value *(A)* was 1 for each task participant completed successfully and 0, otherwise.

One accuracy measure was calculated for each group of participants for each task. The measure was the proportion of the number of times participants completed the task accurately compared to the total number of participants in the group.

7.6.3 Lostness

Lostness *(L)* is a scale composed of the number of unique and total pages visited by the participant in comparison to the optimal number of page visit required to complete the task (Smith, 1996). In this study, the optimal number refers to the minimum number of page views required for the task. Smith (1996) described a user as definitely 'lost in a hyperspace' if the lostness score was greater than 0.5 and any score less than 0.4 as 'not lost'.

To calculate the score, she proposed the following equation:

$$L = \sqrt{(D/T - 1)^2 + (R/D - 1)^2},$$

where

T = Total number of pages visited by a participant in a task
D = Number of distinct pages visited by a participant in a task
R = Minimum number of page visits required to complete a particular task.

7.6.4 Efficiency

Efficiency *(E)* deals with the total number of page views versus the minimal or optimal number of page views and the accuracy of task completion. It is correlated with lostness but not perfectly, as users with the same lostness may vary in efficiency (Smith, 1996). Efficiency measure was calculated using another equation proposed by Smith. A low score in this scale indicated more efficiency. The equation is as follows:

$$E = \sqrt{(D/T - 1)^2 + (R/D - 1)^2 + (A - 1)^2}\ .$$

7.6.5 Tool selection preference

Participants differed based on their preference of selecting navigation tool. For this measure, the percentage of clicks on the Back button *(BC)* with respect to total clicks *(TC)* were calculated. The goal of this analysis was to find out how the users selected or moved away from the Back button based on the available tools for a particular task.

8 Results

The analysis was carried out using the statistical analysis software, SAS® v-9.1. The standard procedure MIXED in SAS® was used to conduct the analysis. The procedure used *two-way repeated measure analysis of variance* to test the hypotheses. As the task settings were identical, except for the type of breadcrumbs present, *Breadcrumb type* was another factor in the experiment. It took either of two values: *RBC* or *EBC*, based on the breadcrumb type present in the task. The analysis used breadcrumb type as the within-subject factor and spatial ability as the between-subject factor and α was set at 0.05. The analysis also investigated the interaction effect between spatial ability factor and the other independent factor: breadcrumb type, in order to explain the results in more detail. It was assumed that the data values of each dependent measures, taken in the experiment, followed a normal distribution and there was no hidden pattern in the residuals of the values. Model diagnostics in SAS® were run to see if there were any underlying patterns in the data points. The analysis showed no noticeable departure from the assumptions.

8.1 Speed

The statistical analysis about the effect of spatial ability on speed did not reveal any significant result. Although it was found that participants with high spatial ability had less mean speed (463.6 sec.) than that (525.2 sec.) of participants with low spatial ability, the difference was not significant. Furthermore, there was no significant interaction effect between spatial ability and breadcrumb type.

8.2 Lostness

No significant effect of spatial ability on lostness was found from the analytic statistics. Although the statistics on lostness show that participants with high spatial ability were less lost on average (0.75) than participants with low spatial ability (0.81), the average difference was not statistically significant. In addition, there was no interaction effect found between spatial ability and breadcrumb type.

8.3 Efficiency

Participants with high spatial ability were more efficient (*i.e.*, had low efficiency scores) than the participants with low spatial ability. The standard deviations in the efficiency scores of two groups of participants were close and the values were almost equally dispersed. Table 1 presents the descriptive statistics on both groups of participants.

Table 1 Descriptive statistics about the effect of spatial ability on efficiency

	Spatial ability score	
	Low	*High*
Mean	1.05	0.84
Standard error	0.07	0.08
Median	1.07	0.89
Standard deviation	0.35	0.38
Range	0.17–1.51	0.00–1.41

After running the analytic statistical procedure, a significant main effect of spatial ability was found on the efficiency of the participants ($df = 1$, F-value = 4.38, $Pr > F = 0.0486$). This value rejected the null hypothesis that spatial ability would have no effect on the efficiency of participants. A further analysis of the interaction of spatial ability with condition showed no significant outcome. The Least Square Means were calculated for two groups of participants and are presented in Table 2. Participants with high spatial ability had an estimated mean efficiency score of 1.05. The estimated mean from the Least Square Means analysis for participants with low spatial ability was 0.85.

Table 2 Least square means statistics on efficiency about the main effect of spatial ability

Spat. Ab.	*Est. mean (Score)*	*DF*	*t-Value*	*Pr > |t|*	*Range (Score)*
Low	1.05	21	15.46	< .0001	0.91–1.19
High	0.85	21	11.99	< .0001	0.70–0.99

8.4 Tool selection preference

Descriptive statistics about the effect of spatial ability on tool selection preference are shown in Table 3. Participants with high spatial ability used the Back button less than the participants with low spatial ability.

Table 3 Descriptive statistics about the effect of spatial ability on percentage of back button click

	Low Sp. (%)	*High Sp. (%)*
Mean	20.3	12.9
Standard Error	3.0	2.0
Median	19.1	8.6
Standard Deviation	15.2	10.0
Range	0.0–41.8	0.0–34.0

The difference in using Back button in Table 3 came as marginally significant after the hypothesis testing ($df = 1$, F-value = 4.16, $Pr > F = 0.054$; $df = 21$, t-value = 2.12, $Pr > |t| = 0.0462$). Although $Pr > F$ is marginally greater than the significance level (0.05), the t-value and $Pr > |t|$ reported by the procedure MIXED rejected the null hypothesis that spatial ability would have no effect on tool selection preference. Least Square Means were calculated for both group of participants and are presented in Table 4. There was no significant interaction effect found between spatial ability and breadcrumb type.

Table 4 Least square means statistics on percentage of Back button click about the main effect of spatial ability

	Spatial ability lower-upper (%)	*Est. Mean (%)*	*DF*	*t-value*	*Pr>|t|*
Low	20.6	21	7.90	<.0001	15.1–26.0
High	12.9	21	4.78	0.0001	7.3–18.5

8.5 Accuracy

The accuracy score of a participant was 1 if the task was completed successfully, or 0, otherwise. An overall accuracy score was calculated, using the accuracy scores for the tasks performed by low spatial ability participants, by taking the proportion of the total number of success in task completion compared to the total instances of such tasks. Another similar score was calculated using the accuracy scores for the group of participants with high spatial ability. Table 5 shows the result of accuracy score between two groups of participants.

Participants with high spatial ability were more successful than participants with low spatial ability in terms of the overall accuracy score of the group.

Table 5 Accuracy measure of participant groups with low and high spatial ability

	Overall accuracy score
Tasks by Low Sp. ($N = 26$)	0.50
Tasks by High Sp. ($N = 24$)	0.79

9 Discussion

The analysis in the previous section revealed that spatial ability had a significant main effect on the efficiency. Participants with high spatial ability were more efficient than participants with low spatial ability. Besides, participants with high spatial ability used the Back button less than participants with low spatial ability, and the difference came as marginally significant. The main effect was absent for the speed and lostness measures. However, this outcome supports the previous studies on other information spaces stating that spatial ability influences navigation performance in information space. Further analysis showed that participants with high spatial ability had more overall accuracy score than participants with low spatial ability in all task arrangements. However, due to the nature of these measures, no statistical significance analysis was done and the results can be taken as informal but guiding towards future prediction. This study also investigated the relationship between the spatial layout of breadcrumbs and spatial ability of people. The spatial layout of experimental breadcrumbs did not affect the participants with high and low spatial ability, which might have indicated that breadcrumbs can be accepted as a navigation tool for people with a wide variety of spatial ability.

10 Conclusion

In this study, we have reviewed previous efforts in explaining the relation between spatial ability and navigation in information space. We proposed a tool for navigation in large hierarchical websites. We found a significant difference between high and low spatial ability participants in navigation efficiency. The result also indicated that low spatial ability participants preferred browser's Back button more than high spatial ability participants. This result will help in the development of future web browsers. However, the experimental tool did not interact with spatial ability in navigation performance, which indicated that more spatial concepts like spatial hypertext can be investigated more intensively in web-based systems. Finally, it seems clear from this study that additional efforts are needed to come up with a more effective and usable navigation scheme for people with diverse individual differences.

References

Allen, B. (1998) 'Information space representation in interactive systems: relationship to spatial abilities', *Proceedings of the Third ACM Conference on Digital Libraries*, Pittsburgh, PA, USA, pp.1–10.

Benyon, D. (2001) 'The new HCI? Navigation of information space', *Knowledge-Based Systems*, Vol. 14, No. 8, pp.425–430.

Benyon, D. and Murray, D. (1993) 'Developing adaptive systems to fit individual aptitudes', *Proceedings of IWIUI*, Orlando, FL, USA.

Caplan, B. and Romans, S. (1998) 'Assessment of spatial abilities', *Neuropsychology, Plenum Press*, New York, USA, chapter, pp.379–419.

Chen, C. (2000) 'Individual differences in a spatial-semantic virtual environment', *Journal of the American Society for Information Science*, Vol. 51, No. 6, pp.529–542.

Coone, L. and Fisher, R. (1998) 'Cognitive psychology on memory', *Technical Report*, http://www.scism.sbu.ac.uk/inmandw/tutorials/memory/g1.htm.

Dahlbäck, N. and Lonqvist, P. (2000) 'Navigation and learning – a cognitive analysis of user tasks in electronic information spaces', *Short Paper in CHI '2000*, Amsterdam, The Netherlands.

Dahlbäck, N., Höök, K. and Sjolinder, M. (1996) 'Spatial cognition in the mind and in the world: the case of hypermedia navigation', *In Proceedings of CogSci96*, San Diego, CA, USA, July.

Dieberger, A. (1997) 'Navigation metaphors and social navigation in information spaces', *Position Paper for the Conference on Computer Human Interaction (CHI)'97.*

Dillon, A. (1991) 'Readers models of text structures: the case of academic articles', *Man-Machine Studies*, Vol. 35, pp.913–925.

Dillon, A. (1995) 'What is the shape of information? Human factors in the development and use of digital libraries', *SIGOIS Bulletin*, Vol. 16, No. 2, pp.32–34.

Dillon, A. and Vaughan, M. (1997) 'It's the journey and the destination: shape and the emergent property of genre in evaluating digital documents', *New Review of Multimedia and Hypermedia*, Vol. 3, pp.91–106.

Edmonds, A. (2003) 'Uzilla: a new tool for web usability testing', *Behavior Research Methods, Instruments, and Computers*, Vol. 35, No. 2, pp.194–201.

Egan, D. (1988) 'Individual differences in human-computer interaction', *Handbook of Human Computer Interaction*, Amsterdam, The Netherlands, chapter.

Ekstrom, R., French, J., Harman, H. and Dermen, D. (1976) *Manual for Kit of Factor Referenced Cognitive Tests*, Educational Testing Service, Princeton, NJ, USA.

French, J., Ekstrom, J. and Price, L. (1963) *Kit of Reference Tests for Cognitive Factors*, Educational Testing Service, Princeton, NJ, USA.

Hewett, T. (1998) 'Cognitive factors in design: basic phenomena in human memory and problem solving', *Proceedings of the Conference on Computer Human Interaction (CHI)*, pp.117–118.

Hochheiser, H., Kositsyna, N., Ville, G. and Shneiderman, B. (1999) 'Performance benefits of simultaneous over sequential menus as task complexity increases', *Technical Report CS-TR-4066*, http://citeseer.ist.psu.edu/article/hochheiser00performance.html.

Höök, K. and Dahlbäck, N. (1997) 'Designing navigational aids for individuals', *Submission to CHI97 Workshop on Navigation in Electronic Worlds*, Atlanta, GA, USA, 23–24 March.

Instone, K. (2002) 'Location, path and attribute breadcrumbs', *Proceedings of the 3rd Annual Information Architecture Summit*, 16–17 March, http://keith.instone.org/breadcrumbs.

Lohman, D. and Kyllonen, P. (1983) 'Individual differences in solution strategy on spatial tasks', *Individual Differences in Cognition*, Academic Press, chapter, Vol. 1, pp.105–135.

Neerincx, M. and Lindenberg, J. (1999) 'Supporting individual situation awareness in web-environments', *Proceedings "Ergonomie in uitvoering" Conference*, The Netherlands, 12–13 November, http://www.cwi.nl/projects/uwish/papers/sapaper.pdf.

Robertson, G. (1997) 'Navigation in information spaces', *Submission to CHI97 Workshop on Navigation in Electronic Worlds*, Atlanta, GA, USA, 23–24 March, research.microsoft.com/~ggr/navigation/navigation.doc.

Smith, P.A. (1996) 'Towards a practical measure of hypertext usability', *Interacting with Computers*, Vol. 8, No. 4, pp.365–381.

Stanney, K. and Salvendy, G. (1995) 'Information visualization: assisting low spatial individuals with information access tasks through the use of visual mediators', *Ergonomics*, Vol. 38, No. 6, pp.1184–1198.

Tulving, E. (1983) *Elements of Episodic Memory*, Oxford, Oxfordshire, New York: Clarendon Press: Oxford University Press.

van Dyke Parunak, H. (1989) 'Hypermedia topologies and user navigation', *Proceedings of the Conference on Hypertext*, pp.43–50.

Vicente, K. and Williges, R. (1988) 'Accomodating individual differences in searching a hierarchical file system', *International Journal of Man Machine Studies*, Vol. 29, pp.647–688.

Zaphiris, P., Shneiderman, B. and Norman, K. (2002) 'Expandable indexes versus sequential menus for searching hierarchies on the world wide web', *International Journal of Behaviour and Information Technology*, Vol. 21, No. 3, pp.201–207.

Note

1 http://www.uzilla.net