Impact of Spatial Visualization Aptitude on WWW Navigation

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Abstract: Although the underlying mechanism is not well understood, there is considerable evidence that the constellation of cognitive factors known as 'spatial aptitude' influences users' performance in information spaces. Evidence of the effect in the computer science literature is contradictory: some studies show that techniques, which support users with lower aptitude, retard performance by those with higher aptitude. We have investigated the effect of the visualization subfactor in a real-world navigation task using location menu breadcrumbs and Dillon's IMRD task.

We compared the navigational styles and success rates in an answer-seeking task using both standard and menu breadcrumbs in a large website. Although we did not find any difference in terms of speed or navigational confusion, we did find that the higher aptitude group was significantly more efficient. Also, members of the higher aptitude group used the Back button marginally less than the lower aptitude group.

1. Introduction

The so-called lost-in-hyperspace phenomenon is a well-known hindrance to achieving the potential of hypertext to improve the human condition. That phenomenon is now often termed 'the navigation problem' presupposing both a cause and solution. In open problems, such as navigation, where people must form plans as part of their solutions, individual differences are often an important predictor of likely success (Benyon & Höök, 1997; Charney, 1994). There is a long tradition of trying to understand the fundamental reasons that hypertext succeeds (or does not) (Charney, 1987; Nielsen, 1989; Wright, 1991). Chen and Rada (1996) were surprised to find, in their meta-analysis of 23 experiments, that so-called 'spatial ability' was the only individual difference that had a measurable effect on success with hypertext (in terms of efficiency or effectiveness). We chose the further investigate the role of spatial aptitude on styles of, and success in, hypertext navigation. We use a large hierarchically structured website to make the study realistic and relevant as such websites abound. A further advantage of our selection is that key properties of navigation in such structures are well known (Larson & Czerwinski, 1998).

This work is in two parts: (1) an analysis of spatial aptitude data collected as part of an experiment presented earlier (Blustein et al., 2005); and (2) an outline of our ongoing follow-up to that study.

1.1 Spatial Visualization Aptitude

Spatial aptitude is the property of mind that requires several psychological attributes such as aptitude to encode information, remember, transform and differentiate spatial objects (Lohman & Kyllonen, 1983). Carroll (1993) performed an exploratory survey that yielded five factors of spatial aptitude belonging to the visual perceptual domain: visualization (VZ), spatial relations (SR), closure speed (CS), closure flexibility (CF), and perceptual speed (PS). Spatial visualization has been found as the most important factor among the factors of spatial aptitude that influence navigation in The WWW (Carroll, 1993; Sjölinder, 1996; Vicente & Williges, 1988). SV is the "ability in manipulating visual patterns, as indicated by level of difficulty and complexity in visual stimulus material that can be handled successfully, without regard to the speed of task solution" (Carroll, 1993, p. 362). Throughout the rest of this article, the term name spatial aptitude will refers to the constellation of individual's psychological measurements of VZ (the aspect of spatial aptitude that is found influential for navigation). Spatial visualization requires either the mental restructuring of a figure into components for manipulation or the mental rotation of a spatial configuration in short term memory, and it requires performance of serial operations, perhaps involving an analytic strategy (Ekstrom et al., 1976). It was noted that some test participants may use a strategy not involving mental rotation of images.

1.2 Navigational Tools on The Web

Much research has been conducted to determine what cognitive processes are involved when users interact with Web browsers. Popular Web browsers provide some navigation-aiding tool to help navigation.

'Back', 'Forward', and 'History' buttons are most commonly seen in this category. During navigation, they tend to utilize the tools to refrain themselves from being disoriented or misled from the original destination.

Breadcrumbs are commonly seen in large, hierarchical websites, such as the Yahoo! Directory. Breadcrumbs on a page aim to help users by providing information on their location in the site (Blustein et al., 2005). They also facilitate in revisiting previous pages if the user does not reach the current page from a search result or is not redirected from another site. Figure 2 shows an example of menu breadcrumbs (Blustein et al., 2005). This variation of regular breadcrumbs present the part of site structure in a two-dimensional hierarchical way through the in-place expandable menu layout. Section 2 discusses the influence of spatial organization of information on navigation performance. The two-dimensional spatial layout of menu breadcrumbs is one of the aspects that were investigated in the earlier study.

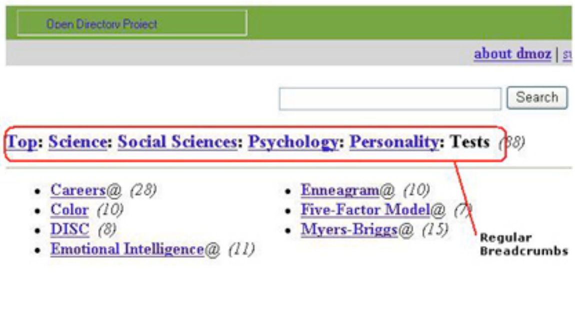

Figure 1. An example of regular breadcrumbs

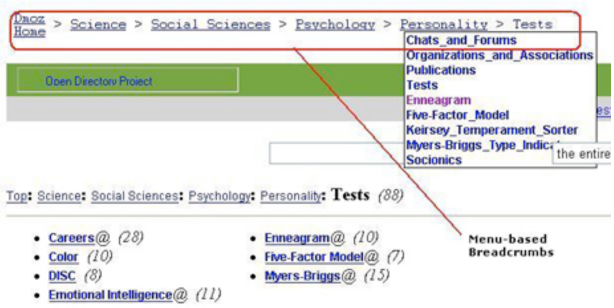

Figure 2. An example of menu breadcrumbs

1.3 Purpose of the Work

Briefly, our goal in this study is to gain understanding of how people differ when they navigate large, hierarchical sites. In particular we are working to develop models of user cognition for use in user-centred design of better tools for using hypertext on the WWW.

Many reports of the influence of spatial aptitude on success with hypertext refer to simulated physical worlds, e.g. the 3D VRML-based information structure used by Chen (2000). However, the cognitive processes used in such simulations, and indeed in navigating in the physical world, are different from those used when processing text (Kolb & Whishaw, 2003, p. 573). This article is about the interaction of spatial aptitude and success in using hypertext that is not similar to navigating in the physical world. Although we include hypermedia in our working definition of hypertext, we are studying presentations that are primarily text-based.

2. Background

It is not entirely clear how people conceptualize the whole interaction environment and how much that conception spatial. Paivio's (1990) work on mental processing of information demonstrated that the aptitude to encode conceptually presented information into a spatial representation in a reader's mind could help in learning and memory. Another study reports that short term memory influences navigation The aptitude to represent conceptually connected information, mentally in a spatial way may help to reduce problems such as lost in hyperspace and cognitive overhead (Ahmed & Blustein, 2005).

Dillon (1991, 2000) suggests that readers might form mental representations of the texts they read which combine physical and logical characteristics. He terms this 'information shape'. If his supposition is correct then readers likely use those models to navigate in the 'space' of the text (Spence, 1999). Navigation becomes especially important in hypertext, particularly where the components texts (e.g. paragraphs) are non-contiguous (Bernstein, 1998; Charney, 1994). Before we discuss this idea further we present a brief review of key experimental results.

2.1 Previous Key Results

Much research reported the relation between spatial aptitude of an individual and navigation in information space (Benyon & Murray, 1993; Chen & Rada, 1996; Egan, 1988). Vicente and Williges (1988) found that spatial aptitude influenced the user's aptitude to navigate a large file structure. Benyon and Murray (1993) found that a combination of spatial aptitude and computer experience affected users' aptitude to interact with a database system.

Spatial organization of information allows scanning large quantities of information with little effort. When the information units are connected topologically, any linear, two dimensional, tree like hierarchical or three dimensional information layouts can be considered as spatial representation (Mark, 1999). The consensus view amongst researchers in this field that textual can be considered spatial only if the presentation has more

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than one dimension (Allen, 2000; Stanney. & Salvendy, 1995; Vicente & Williges, 1988). Some studies concluded that navigation performance of people with lower spatial aptitude improved by providing them with visual tool that assisted in understanding the layout of the space (Allen, 2000; Stanney & Salvendy, 1995). But, results from some other studies did not agree with this outcome. Some studies showed that visual presentation of information did not have any effect in navigation of users with low and high spatial aptitude (Chen, 2000; Vicente & Williges, 1988).

Wiebe (1991) reported that spreadsheet like representation of nodes helped people in quick learning of relationship among nodes. In a study by Vicente and Williges (1988), participants performed navigation using both verbal and visual file system. They used the concept of 'momentum' referring to how participants integrated and extracted information from different interfaces. The result showed that the performance difference within participant group was not significant across the interfaces. Stanney & Salvendy (1995) found that visual tools, such as two-dimensional and three-dimensional organization of information, removed the discrimination of mental models between people with low and high spatial aptitude. They designed three structures of information representation: (1) click-based exploration, (2) hierarchical, and (3) purely linear. They concluded that participants with low spatial aptitude could not use the first interface due to failure to create a mental representation of the information. But no difference in performance was found between participants with low and high spatial aptitude for either of the other representations. In studies of searching bibliographic records Allen (2000) found that participants with low visualization spatial aptitude performed better with two-dimensional representations of information however the same design features deteriorated performance of participants with high spatial visualization aptitude. Dahlbäck et al. (1996) found that visual navigation aids, in hypermedia, provided help to people with low spatial aptitude. The information structure used in this study was an online, hypermedia based help system. Campagnoni & Ehrlich (1989) reported that a good spatial aptitude helped one to learn the structure of the domain quickly. In the study, participants with higher visualization spatial aptitude used the top-level table of contents less frequently than participants with lower visualization spatial aptitude. Leidig (1992) only found a marginal effect of spatial aptitude on the accuracy of performance when using hypertext structure maps, although a significant effect of spatial aptitude on users' general satisfaction was reported.

2.1 Summary of Previous Work

Previous studies had the limitation that none of those investigated the performance of people with diverse spatial aptitude during navigation in large Web environment.

Readers navigate to revisit and explore parts of a text. It could well be that all readers use a form of mental representation for navigation, as hypothesized by Dillon (2000), and that this representation is closely tied to the VZ factor of spatial aptitude. The apparent contradiction posed by the inverse relationship of high spatial aptitude and poor performance (and vice versa) in some studies could be due to interference between the reader's internal representational mechanism and the specific representation used in the hypertext (McKendree et al., 1995).

The results of previous studies suggest that spatial aptitude somehow influences how readers perceive and use hypertexts. The applications to information systems on the WWW are obvious. If we could understand how and why these differences affect users there could be substantial changes to the design of websites and the experience of using the WWW: Adaptive hypermedia techniques could be used to tailor the presentation of information; Users with particular needs (perhaps researchers who now spend hours 'on' the WWW daily) would perform better with specialized training (Upitis et al., 1994).

3. Hypothesis

An early step in understanding this phenomenon is to determine how spatial aptitude affects the use of websites. We confine our interest to large hierarchically-structured websites at first (e.g. Yahoo!, Open Directory Project, Wikipedia) since they are frequently used information sources, the effects of their structure has been studied extensively in the cognitive psychology literature, and although they are hypertextual their structure is not erratic (Brockmann et al., 1989; Larson & Czerwinski, 1998).

We hypothesized that spatial aptitude would be a significant factor in navigation. We also hypothesized that there would be an interaction between spatial aptitude and the ways breadcrumbs were presented.

4. Method

Before performing navigation tasks, each participant took part in two paper-pencil based tests to assess spatial aptitude. The navigation part of the study used two conditions of task set. Each task was to navigate to a destination page, as the question demanded, in a large, hierarchical website. Each condition had four such tasks with alternating sequence of presence of regular and menu breadcrumbs along with other navigational aid in the browser. The tasks were organized in a crossover design. The first two tasks were specified as practice session and the last two as the test session. Participants were assigned to conditions in a predetermined sequence to maintain balance.

4.1 Website and Data Extraction

The study required a large hierarchical website where a meaningful hierarchy exists. The Open Directory Project site (URL:http://www.dmoz.org/) is such a site. At the time of the study it contained more than 4 million site references having approximately 64,739 editors and over 590,000 categories. The web pages for this experiment are permitted for use according to the free use license of Open Directory Project. The whole site was downloaded for the experiment. Once copied, we reproduced a different version of the whole Open Directory Project site in which menu breadcrumbs were inserted in each page.

4.2 Participants

The twenty-six unpaid volunteer participants of the experiment were graduate (n=16) and under graduate (n=10) students of Dalhousie University. Sixteen participants were from Computer Science discipline and seven were from 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 (namely 12). There were nineteen male and seven female participants and all of them were familiar with the WWW environment and spend an average of 6–10 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 but was used in the range of spatial aptitude scores.

4.3 Instructions to the Participants

Before beginning spatial aptitude tests, each participant was given sufficient time to understand the tests from the instruction sheet. The tests were started only when participant agreed to begin. Participants were informed that the tests measured an aspect of their spatial aptitude and the use of any physical object to answer the questions was prohibited.

Participants were neither encouraged nor discouraged to prefer any of the navigation tools. They were also told about the procedure of the experiment. Each of them was given computer-based instructions to look for the answer in the pages and to avoid visiting external pages. The functions of the buttons in the browser toolbar were also explained at the beginning of each online part of the study.

Participants were not allowed to open multiple windows of the browser and prohibited to use the search feature of the experiment websites. In case, they used the search feature or reached an external page from the site, they browser directed the request to a default page at <URL:file://external.html>. Participants could easily get back to the experiment site from that page by clicking the Back button or a link titled ‘Click here to go back to the last visited page’. Participants who were not done a task within twelve minutes were reminded that they could quit that task and start the next one at anytime.

4.4 Spatial Aptitude Tests

In this study, spatial visualization aptitude was assessed using the paper-pencil based paper folding test (VZ-2) and surface development test (VZ-3) taken from the Kit of Factor-Referenced Cognitive Tests (Ekstrom et al., 1976). Many studies use these tests to measure the effect of spatial aptitude on success with hypertext (Allen, 2000; Blustein & Satel, 2003; Stanney & Salvendy, 1995). Furthermore, these tests have been used in cognitive psychology research (Downing et al., 2005).

4.5 Data Acquisition

For data acquisition purpose, a customized usability testing service Uzilla was used in the study. Uzilla is an instrumented Web browser that logs user interaction details like clicks, mouse downs, mouse over and scrolling with the Internet based systems into its integrated, analysis and aggregation data collection server (Edmonds, 2003).

4.6 Independent Variable

Spatial aptitude, the independent variable was measured as the sum of scores on the VZ-2 and VZ-3 tests. Answers were corrected for guessing following the standard procedure described in the Manual and instructions given to the participants (Ekstrom et al., 1976). As there are no global standards for those tests, the results are always compared within the participant population. Figure 3 shows an unusually demarcation between the groups in our experiment. Such a clear difference is unusual in the spatial aptitude literature — it makes our results the more striking.

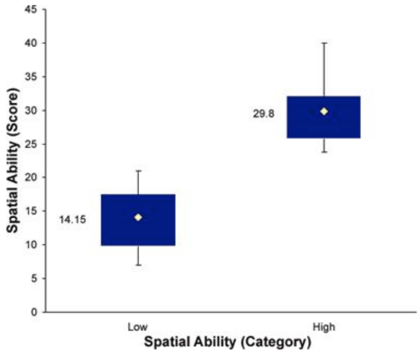

Figure 3. Distribution of spatial aptitude scores
(boxes depict 25th – 75th percentile, whiskers depict range)

Of the twenty-six participants, there were 13 participants for both Conditions. The participants were evenly partitioned into two groups: 'lower' and 'higher' by the median (21.38) of the spatial aptitude scores. However, after classification for Condition 1 there were 7 participants in the lower spatial aptitude group and 6 participants in the higher spatial aptitude group. For Condition 2, there were 6 participants in the lower spatial aptitude group and 6 participants in the higher spatial aptitude group. For this condition, one participant who faced problem in understanding the language the website, was not considered for the classification.

Median splits are somewhat controversial in the literature (Irwin & McClelland, 2003) largely due to the reduced statistical power (β-level) they give rise to. The earlier experimental literature about spatial ability has relied on this technique. However we expect to use regression analysis for our follow-up studies.

4.7 Dependent Variables

1. Speed was measured as the number of seconds to complete a task. Lower values represent faster speed.
2. Accuracy (A) was 1 if and only if the participant completed the task successfully, and 0 otherwise. One accuracy measure was calculated per group per task. The measure was the division of number of times participants completed the task accurately and total number of participants in the group.
3. Lostness (L) is a scale composed of the number of unique and total pages visited by the participant compared to the optimal number of page visits required to complete the task (Smith, 1996). In this study, the optimal number refers to the minimal number of page views required for the task. Smith (1996) described an 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'.

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

Where
T is Total number of pages visited by a participant in a task.
D is Number of distinct pages visited by a participant in a task.
R is Minimum number of page visits required to complete a particular task.
We plan to analyze the raw data with other measures of 'lostness' (Otter & Johnson, 2000).

4. 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). The lower the value of E the greater the level of efficiency.

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

5. 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) was calculated. The goal of this analysis was to measure users preference for the Back button (which was available for all webpages but only allowed single steps) versus specific tools available in a specific website and for a specific task.

5. Results

We applied 2-way repeated measure analyses of variance (ANOVAs) to our data. The analysis used breadcrumb type as the within-subject factor and spatial aptitude as the between subject factor. It was assumed

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that the data values of each dependent measures followed a normal distribution and there was no hidden pattern in the residuals of the values. Model diagnostics detected no departure from the necessary assumptions for our analyses. No interaction effects were found in any of the analyses involving spatial aptitude. We present data about the spatial aptitude factor and the various measures described above.

1. Although participants with higher spatial aptitude seemed to be faster than participants with lower spatial aptitude (463.6 vs. 525.2 sec.), the difference was not significant.

2. The apparent difference in lostness for participants with higher spatial aptitude (0.75 on average) and participants with lower spatial aptitude (0.81 on average), the difference was not significant.

3. Participants with high spatial aptitude were more efficient than those with lower spatial aptitude ($df = 1$, F= 4.38, $Pr > F = 0.0486$). Table 1 presents the descriptive statistics on both groups of participants. The critical values and least square means for two groups are in Table 2.

Table 1: Distributions of *Efficiency* measures

	Spatial Aptitude Category	
	Lower	Higher
Mean	1.05	0.84
Std. Err.	0.07	0.08
Median	1.07	0.89
Std. Dev.	0.35	0.38
Range	0.17 - 1.51	0.00 – 1.41

Table 2: Effect of spatial aptitude on *Efficiency*

Spat. Ability (Category)	Range (Score)	LS Mean (Score)	*t* Value	Pr > |*t*|
Lower	0.91 – 1.19	1.05	15.46	< 0.0001
Higher	0.70 – 0.99	0.85	11.99	< 0.0001

4. Participants with higher spatial aptitude used the Back button marginally less than those with lower spatial aptitude ($df = 1$, F = 4.16, $Pr > F = 0.054$; $df = 21$, t = 2.12, $Pr > |t| = 0.0462$). Critical values for both groups are presented in Table 3.

5. There was no significant difference between the overall accuracy scores for participants in the higher and lower spatial aptitude categories (0.8 and 0.5 respectively). Participants with higher spatial aptitude were more successful than participants with lower spatial aptitude in terms of the overall accuracy score of the group.

6. Discussion

The analysis in the previous section revealed that spatial aptitude had a significant main effect on the efficiency: Participants with higher spatial aptitude were more efficient than participants with lower spatial aptitude. Besides, participants with higher spatial aptitude used the Back button less than participants with lower spatial aptitude a difference that was marginally significant. No main effect was detected for either speed or lostness measures. This outcome supports the conclusions of other studies that spatial aptitude influences navigation performance in information space. Further analysis showed that, in all task arrangements, participants with higher spatial aptitude had higher overall accuracy scores than participants with lower spatial aptitude. 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 aptitude of people. The spatial layout of experimental breadcrumbs did not affect the participants with higher and lower spatial aptitude, which might have indicated that breadcrumbs can be accepted as a navigation tool for people with wide variety of spatial aptitudes.

7. Summary Of Experiment

This work has explored the influence of innate spatial visualization aptitude in navigation of large hierarchical websites with novel navigational aids. The outcome has underlined the necessity of further efforts and hinted what it will take to build widely acceptable navigation tools and interfaces for people with diverse individual differences. Even though there was no difference in time taken to complete the (realistic) tasks, readers with higher spatial aptitude used different techniques to navigate the website than their counterparts with lower spatial aptitude.

There is clear evidence of at least two sub-factors of spatial aptitude that have substantial effect on success with hypertext in one of the simplest hypertext conditions (namely, hierarchy). Experimental avenues leading from these results are clear. Practical developments that are likely to follow from such experiments are in ways that software (browsers) and websites can be adapted to suit particular navigational styles. We do not completely reject the notion that users can be trained to work with information systems that are not ideally suited to their cognitive style, however we expect that it will be easier and more profitable to adapt systems to people rather than vice versa.

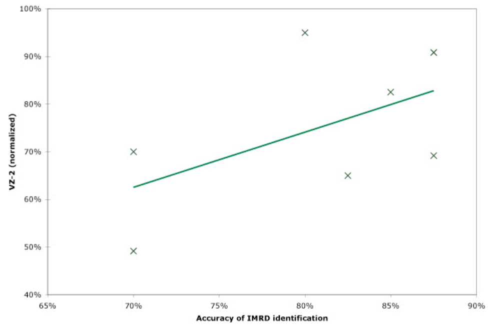

Figure 4. Linear Correlation of VZ-2 Score and Accuracy of Identification of Location of Passages within a Scholarly Work by Expert Participants

8. Ongoing Studies

The study reported above can be extended into several directions. The various components of possible work include spatial aptitude and broader perspective of human cognition and navigation metaphor of the World Wide Web. Some independent parameters appear to affect spatial aptitude such as gender, age, personality factors and other various cognitive styles (Sjölinder, 1996). It may be useful to include these aspects in future studies.

It is especially apt to examine the basis for Dillon's concept of information shape, which we descried briefly in Section 2. We have begun to reproduce the experiment he and Schaap used to test experts on their categorization of logical units within human factors literature (Dillon & Schaap, 1996) in combination with tests of spatial aptitude. Following the method described in their publications we have conducted nine tests, from which seven participants were identified as experts. We have not completely analysed that data yet and are hoping to recruit more experts. In the meantime however we can report that a slightly linear correlation appears to exist between aptitude for the VZ-2 (paper-folding task) factor and categorization of logical units. Figure 4 shows $r = .55$. The linearity is much lower if the non-experts are included in the computation of Pearson's r.

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