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The effects of spatial layout on relationships between performance, path patterns and mental representation in a hypermedia information search task

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The purpose of this study is to build on previous research in hypermedia by including an investigation of the relationships between navigation tools, path patterns and mental representations with traditional measures of navigation outcomes. We examined the effects of four different spatial layouts on three facets of hypermedia use, performance, path patterns and mental representation, during an information search task. Typically, such measures are evaluated independently. We have sought to reveal what types of information in a navigation tool might mediate links between these three aspects of hypermedia use. The performance measures indicated that providing certain types of spatial information does not enhance speed, accuracy or economy but does enhance recall of page titles. Reference is then made to an earlier analysis on the dataset of path patterns using Multidimensional Scaling (MDS) which indicated that users' paths reflected the most prominent type of information provided in the navigation tool. The MDS configurations were then compared to the results of a distance-like ratings task using correlation and regression methods. Only users given explicit spatial cues in the navigation tool exhibited ratings that reflected the paths they had actually taken. Although spatial information may not impact surface performance measures such as speed and economy, spatial information does play a role in influencing where users go and the development of their mental representations of the material in a hyper document.

Keywords: hypermedia, navigation, spatial cues, navigation tool

1. INTRODUCTION

Hypermedia is a system of digitized information (e.g. text, images, audio) connected via hyperlinks. When users work with hypermedia, they often encounter such problems as disorientation (McLeese, 1989; Ransom *et al*. 1997) which can be caused by excessive cognitive overhead (Ransom *et al*. 1997; Tsai, 1988). Disorientation refers to the tendency for users to lose their understanding of their location within a hyper document, which results in a break down of decision-making for where to go next. Cognitive overhead refers to the level of cognitive resources (e.g. attention and memory) that are required to successfully complete a task in hypermedia. In order to lessen these difficulties, it is important for hypermedia designers to understand the relationships between the interface, task demands, user characteristics and user cognitive processes.

Navigation tools are one interface element that can influence user behavior. Basic performance measures such as the speed of a search, the number of pages visited and the accuracy of finding target information have provided much insight into how users are impacted by different aspects of a navigation tool (e.g. Boechler and Dawson, 2002; Boechler and Shaddock, 2004) However, such measures reveal little about how navigation tools might shape the paths that users take through hyper documents and subsequently, what mental representations users hold of the material they've viewed.

In this study, we examined the impact of different navigation tools on traditionally measured performance outcomes (speed, page count, accuracy, recall). In addition, we investigated how elements in the navigation tools impact where users go and the relationship between these path patterns and the mental representations that users develop.

1.1 Hypermedia navigation tools

It has been suggested that hypermedia navigation can be enhanced if users are provided with spatial overviews that represent the structure of a hypermedia document. Spatial tools modeled after real-world navigational aids (maps or diagrams) do enhance performance on some measures (Beasley and Waugh, 1995; Kim, 1999; McDonald and Stevenson, 1998, 1999; Schroeder and Grabowski, 1995). For example, McDonald and Stevenson (1998) found that a spatial map produced faster and more accurate searches in which users accessed less extraneous pages. Dee-Lucas and Larkin (1995) found that access to a spatial map resulted in better recall for the unit titles in a document than using an alphabetical content list.

In contrast, Stanton *et al.* (1992) found evidence against facilitation of navigation maps on effectiveness measures. Subjects who were not given a map outperformed the subjects who were given a map on accuracy of a sentence completion task. Subjects in the no-map condition were also better able to produce a drawing of the document structure and reported feeling more in control of the search situation. Similarly, Leventhal *et al.* (1993) found that correlations between accuracy and speed measures and both the percentage and total number of visits to two types of hierarchical overview cards were not significant. Additional studies have indicated that the impact of spatial overviews on search and retrieval performance is influenced by the difficulty of the task. For example, Padovani and Lansdale (2003) observed that users made use of navigation tools less frequently when time pressure was added to the task. They proposed that using a navigation tool increases the demand on cognitive resources and when the task is difficult users focus their resources on the task rather than the navigation tool.

These results suggest two issues that need to be examined further: First, we need to better understand the specific elements of a spatial overview that may enhance or detract from different aspects of the navigation process. Second, we need to better understand how spatial overviews impact the continuous development of the mental representations users hold of the document content. Through the course of completing an information search task, users extract information about the content of the document from two sources, the navigation tool and the experiences of traversing the document. If the navigation tool is constructed with elements that induce users to traverse the document in ways that reflect its semantic organization then these two sources of information can easily be integrated into a single coherent mental representation of the document. If these two sources are discrepant, then it is a reasonable assumption that the user must expend additional cognitive resources to merge the two together.

In this study, comparisons were made across several navigation tools within a single study with a thoughtful inspection of the visual elements that differentiate these tools. We examined the effects of spatial layout on several measures (performance, path patterns and mental representations) and also examined the relationships between the navigation tools and these measures across the course of navigation. The effects of four different spatial layouts on three facets of hypermedia use were tested: performance, path patterns and mental representation. Performance relates to measures of success on the target task, in this case, an information search task. Path patterns refer to where users actually go during the course of the search task. Mental representations refer to the form of the underlying mental organization of the material that users develop throughout the process.

This paper proceeds as follows. First, we give a brief description of the types of visual devices that can convey information in a spatial overview and how these devices relate to the navigation tools used in the study. Second, we give a brief review of literature regarding path patterns and mental representation. Third, we present the results of the performance measures taken during the information search task and the ratings task that followed. Fourth, we link the current analyses on performance and mental representation to a previous analysis of this data on path patterns.

1.2 The Spatial Properties of Navigation Tools

1.2.1 The Nature of Spatial Depictions

Spatiality can be represented in a multitude of ways within a navigation tool or any other type of spatial overview. Tversky (2001) provides a framework for the types of spatial characteristics that can differentiate one overview from another:

> "For spatial arrays, the most basic metaphor is proximity: proximity in space is used to indicate proximity on some other property, such as time or value. Spatial arrays convey conceptual information metaphorically at different levels of precision, corresponding to the four traditional scale types, nominal, ordinal, interval and ratio. These are ordered inclusively by the degree of information preserved in the mapping (p. 89)".

Different visual devices or elements are used to convey information at each of these levels. For example, spatial arrangements depicting nominal data use spacing (between words, by rows or columns), enclosing structures (e.g. brackets, boxes or circles) and visual devices (e.g. color and shading) to convey conceptual relations. An example of a nominal display would be a simple random list. Similarly, ordinal relationships can be illustrated using all of these elements plus elements such as simple subordination, indentation, size, superpositioning, highlighting and punctuation. These additional elements are used to indicate some order or ranking of items with respect to one or more properties. An example of an ordinal depiction would be a hierarchically ordered list. Interval and ratio displays represent all of the information about spatial proximity conveyed by nominal and ordinal depictions with the added constraint that the distances between elements are meaningful (e.g. X,Y graphs). In the case of ratio data, an absolute zero point is an additional characteristic of such a depiction.

In the current study, subjects navigated through a 22-page hyper document on the topic of Fungi, searching for answers to a number of specific questions. Each hypermedia page contained a short text section and a picture to help users differentiate between pages (see Figure 1).

In order to find the answers to the questions, subjects had to interact with one of four different

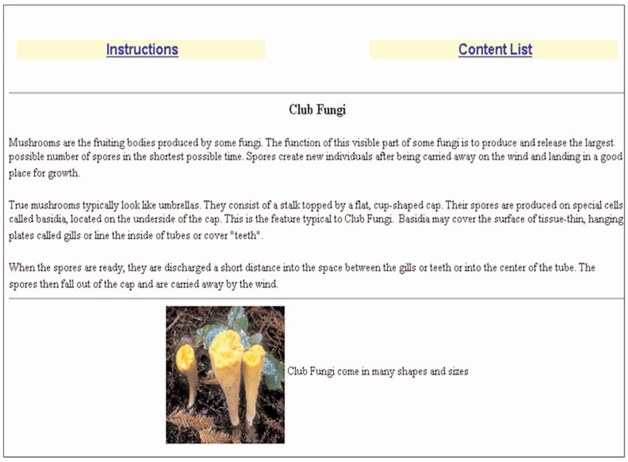

Figure 1 Example of a hyper document page

navigational tools that organized the pages of the hyper document: alphabetical, hierarchical, spatial, or spatial/hierarchical. The diverse naming of these tools suggests that they are designed to organize a subject's search through the hyper document in radically different ways. For instance, one might expect that an alphabetical navigational tool is not spatial at all, while the reverse might be expected to be true of a spatial navigational tool. However, it is important to realize that all four of these navigational tools are spatial in nature, and, following Tversky (2001), can be distinguished from each other as offering differing degrees of conceptual mapping based on the spatial proximity metaphor and the devices that convey proximity. This point is highlighted in the sections that follow, which describe each navigational tool – and its spatial properties – in turn.

Anti-rejection Drug
Biocontrol
Caterpillar Tonic
Chytrids
Club Fungi
Conjugation Fungi
Disease
Food
Fungi
Heart
Lichen
Medicine
Morels
Negative Aspects
Penicillin
Poisonous Mushrooms
Positive Uses
Sac Fungi
Skin
Truffles
Types
Yeast

Figure 2 The Alphabetical Navigation Tool

1.2.2 The Alphabetical Tool

The alphabetical navigation tool is a content list of the hyper document's page titles organized alphabetically. It was intended to deliver minimal spatial information and minimal conceptual information (Boechler and Dawson, 2002), because the list provides no suggestion as to how the page titles may be semantically related (see Figure 2). However, this aid is clearly spatial in the sense that it is displayed as a two-dimensional array of navigational anchors when displayed as a web page on a subject's computer monitor. Using Tversky's (2001) descriptions as a framework to categorize these depictions, the alphabetical list is a spatial depiction at the nominal level, using the device of grouping. In this case, the grouping indicates that each item belongs to one single category. Furthermore, the spatial proximity metaphor is employed in the sense that two items in this tool that are near one another are more alphabetically related (but not semantically related) than are two items that are positioned further apart.

1.2.3 The Hierarchical Tool

The hierarchical navigational tool was similar to the alphabetical tool in the sense that it was also a list. However, the order of items in this list was changed in such a way that spatial proximity was more likely to reflect a semantic relatedness between two items (Boechler and Dawson, 2002). In particular, when two items belonged to the same subordinate category and were close together in the list, they were semantically related. This spatial portrayal of semantic information was not perfect, though, because neighboring items could be less semantically related if they belonged to different levels of categories (e.g. if one was a page, such as "Caterpillar Tonic" and the adjacent item was a category label, such as "Food"). This type of problem was dealt with in the hierarchical tool by including additional visual elements to preserve a greater degree of conceptual mapping. The hierarchical tool designates the superordinate and subordinate categories in the material through the use of font size and label color (Figure 3).

With respect to Tversky's (2001) account of spatial properties, the hierarchical list is a spatial depiction at the ordinal level as the hierarchical indicators (font size, color and superposition) create a conceptual order. This depiction would be considered partially ordered as some elements take precedence over others (e.g. the top label "Fungi") but all elements are not ordered with respect to a single property.

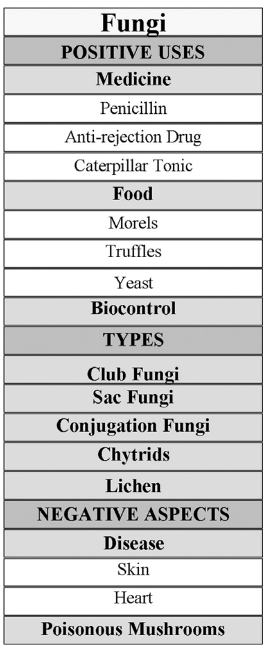

Figure 3 The Hierarchical Navigation Tool

1.2.4 The Spatial Tool

The spatial navigational tool made use of increased space between labels and the clustering of subsets of labels to preserve conceptual mapping (Figure 4). This tool was created by first computing "distances" between pages by counting the number of steps between titles in a hierarchically ordered tree diagram of the material (Boechler and Dawson, 2002). The resulting "distances" were then transformed into a matrix of correlations that was analyzed using multidimensional scaling (MDS). The configuration produced by this analysis provided the positions for the page labels in Figure 4.

Because it was created in this fashion, when viewed from Tversky's (2001) perspective the spatial tool is a partially-ordered depiction at the ordinal level but it uses the device of dispersed space and

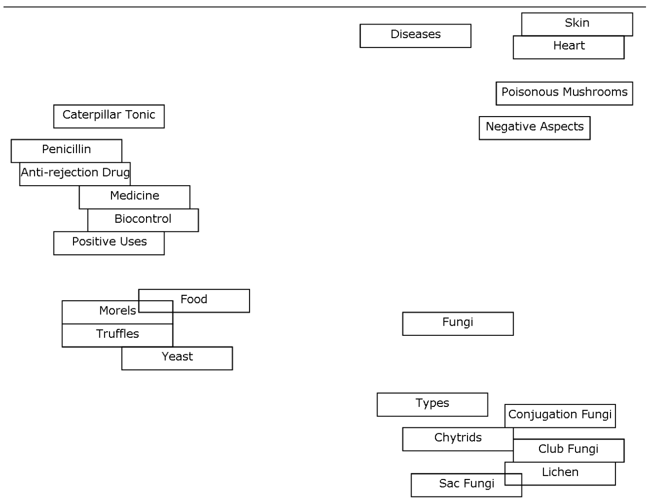

Figure 4 The Spatial Navigation Tool

subset clustering to preserve conceptual relations. This point is elaborated in the paragraphs that follow.

MDS is a statistical method for uncovering the structural regularities or patterns hidden in a matrix of data and representing that structure in graphical form for easier visual interpretation. The coordinates that create the MDS configuration represent some underlying property of the data and the configuration of points they create illustrates how closely the objects under study are related to each other as a function of this underlying property. In the case of the spatial tool, the coordinates reflect the distances between labels on the tree-diagram, a diagram that has explicit hierarchical categories.

In an MDS analysis, the dimensions that produce the spatial coordinates may be abstract such as the conceptual relatedness between pages or concrete such as the physical distances between page labels on the navigation tool. On a MDS plot, related items are plotted close together and unrelated items are plotted far apart (for examples see Borg and Groenen, 1997). In the case of this MDS configuration, both conceptual relatedness and physical distance are salient factors in the tree-diagram arrangement.

The spatial tool did not provide explicit information about the semantic relatedness of pages but the process described above created a configuration with some implicit information about relatedness given that the clustering of page titles reflected to some degree the conceptual levels of the tree diagram. This approach was chosen over using totally random spatial locations as it is unlikely that a random spatial map would be used as a navigation aid for a hyper document.

1.2.5 The Spatial/Hierarchical Tool

The spatial/hierarchical navigational tool contains two devices for conveying conceptual relations: dispersion of the labels to define the hierarchical layers and explicit connecting lines between labels (Boechler and Dawson, 2002). It is a tree-diagram with the super-ordinate heading of "Fungi", below which are three levels of subordinate categories (see Figure 5). Link connections only occur within the three depth levels of the hierarchy designating the categories of "Positive Uses", "Types" and "Negative Aspects" as distinct subsets. Label locations correspond to their conceptual relationship to other labels. Labels that are conceptually related are closer together in the configuration whereas labels with less semantic relatedness are further apart. As with the spatial tool, a variety of spatial configurations could be used. This particular configuration corresponds to the inherent hierarchical organization of the topic of "Fungi".

In terms of Tversky's (2001) taxonomy of spatiality, the spatial/hierarchical tool also uses dispersed space and subset clustering with the addition of ordered space (the four vertical layers of the tree diagram and the polarity of positive and negative features are reflected in the large horizontal distance between their labels) as well as explicit connecting lines that depict the conceptual relations between elements (see Figure 5).

2. SUMMARY AND IMPLICATIONS

The preceding sections have briefly described four different kinds of navigational aids. All four navigational aids are similar in the sense that each provides a spatial arrangement of labels that can be used to access specific content pages in a hyper document. However, the tools are different in regards to the visual cues that convey relatedness. Differences between the navigation tools revolve

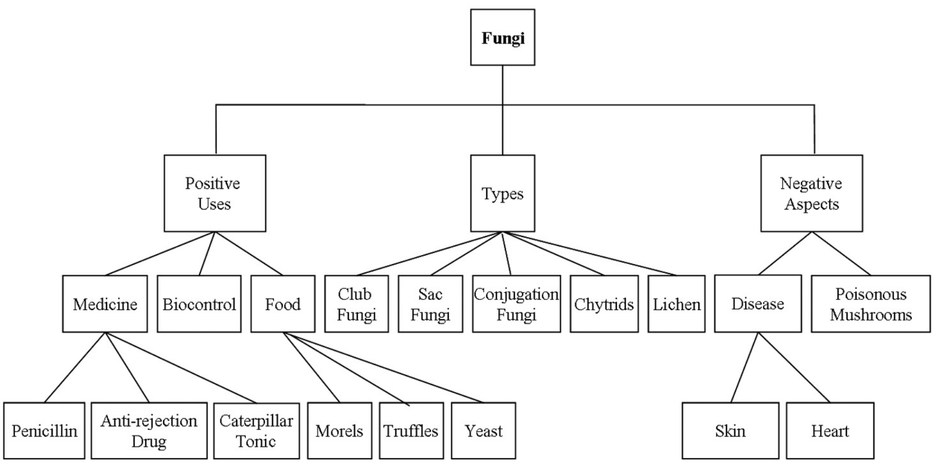

Figure 5 The Spatial/hierarchical Navigation Tool

around precise spatial arrangements of the page labels using proximity as an indicator of semantic relatedness. In some tools, additional cues suggest proximity or relatedness of labels to one another. Some of these cues may be more semantically meaningful than is the case in others.

It would not be surprising to discover that the different navigational tools described above result in differences in navigational behavior, which in turn would produce differences in ability in using the hyper document. For instance, when presented one question, one navigational aid might result in a user searching through pages in one order, while a different navigational aid might lead the same user to answer the same question by examining pages in a different order. Furthermore, these differences might lead to differences in the time taken to answer questions, as well as in differences in remembering information that was discovered, and so on.

If such differences were discovered, then how would they be explained? The explanation couldn't take the form that one tool (e.g. spatial/hierarchical) was spatial, while another (e.g. alphabetical) was not. This is because all of the tools are spatial. Instead, the explanation would have to focus on how differences in spatial arrangements of labels make different kinds of information explicit, or how the semantic relationships between items that they highlight correspond to the representations that a user is creating in semantic memory. For example, if the relationships between items in a navigational tool corresponded nicely to the semantic relationships that were being created in a user's mental representation of the contents of the hyper document, then one would expect efficient search and excellent performance.

In short, an account of the benefits of a particular navigational tool would have to focus upon 1) the relationships between labels in the tool itself, 2) how these relationships altered search behavior through the hyper document, and 3) how the search of the hyper document affected the development of a mental representation of its contents. Some issues concerning the relationship between how a document is searched and the mental representations of document content that result are considered in more detail in the following section.

2.1 Path patterns and mental representation

Path patterns in hypermedia navigation have been examined from a number of perspectives. Several researchers have investigated the linearity of navigation patterns. Andris (1996) found that user's learning styles impacted the degree of linearity in their navigation patterns. Beasley and Vila (1992) found gender differences in linearity where linearity was described as the choice of the next screen in a predetermined lesson sequence. Females tended to navigate in a more linear fashion than males.

Task type or user goals also appear to impact navigation patterns. Beasley and Waugh (1996) found that navigation patterns tended to be top-down, and from left to right during initial learning but were less structured for a review task. Horney (1993) observed that navigation patterns were related to the goals of the user but showed little resemblance to the linearity of the document itself.

Each of these studies addresses a specific characteristic of user path patterns. However, there is little research on the relationships between navigation tools and path patterns. In this paper, reference is made to a previous analysis (Boechler and Dawson, 2002) on this data set using multidimensional scaling to examine user path patterns in relation to the specific navigation tools. The current study extends this prior analysis to also examine relationships between path patterns and mental representations.

2.2 Mental representations

Several studies suggest links between tools with salient spatial properties and users' abilities to recreate the structure of a hyper document as well as differences in performance between users who develop graphical representations and those who don't. McDonald and Stevenson (1997) found that users given a spatial map to help with an information search task subsequently placed more correct node titles on a map of the document than users given a content list or no navigation tool. Kerr (1990) observed that faster users have more accurate and more graphically detailed representations, while slower users tended to give verbal descriptions of the document. These studies imply that navigation tools with certain spatial properties can facilitate the use or development of accurate mental representations of a hyper document.

However, as with the performance literature, there is also evidence to the contrary. For instance, Stanton *et al.* (1992) found that users given a map for navigation were less able to recreate a map of the system than users who were given no navigation aid. Specifically, map users drew fewer primary links and total number of links on an outline of the hypermedia system than users without maps.

As with all mental phenomena, the difficulty in understanding mental representation lies in developing tasks that tap into specific cognitive processes without producing task-induced artifacts. Prior methods for accessing users' mental conceptualizations of a hyper document have included users creating sketch maps (Gray, 1990), filling in blank tree diagrams or outlines of the document (McDonald and Stevenson, 1997), arranging page labels in a configuration and giving verbal descriptions of the format of the document (Kerr, 1990). Such methods tended to force users to create a mental spatial configuration of the document whether or not the navigation tool used was spatial in nature, potentially obscuring the effects of different spatial cues within the navigation tool.

In the current study, to avoid imposing spatial structure on users' responses, a distance-like ratings task was employed to tap into users' underlying mental representations. Users were asked to rate the relatedness of pairs of page titles to reveal their mental organization of the document material. This task rests on the assumption that a distance-like rating reflects a person's subjective perception of the similarity between two items. This is the same premise adopted in similarity judgment studies that have investigated multitudes of types of stimuli (Krumhansl, 1978; Tversky and Gati, 1982). Similarity judgment tasks have been used to discern participants' subjective perceptions of the similarity between countries, geometric figures, letters (Tversky, 1977), and color, line orientation and number (Rosch, 1975). This is also the premise behind semantic differential tasks that more specifically measure the conceptual relatedness of words (e.g. Black, 2001; Chandler and Spies, 1996). Prior research suggests that a semantic distance ratings task produces comparable results to a visual differentiation task (Hofman and Mikaelovicz, 1975) while potentially avoiding the confounds related to creating a spatial configuration.

3. METHODS

3.1 Materials and tasks

3.1.1 The hyper document

Participants were tested on a 22-page hyper document on the topic of Fungi programmed using Visual Basic 6.0 (Boechler *et al*. 2002). Each hypermedia page contained a short text section with similar word counts between pages (approx. 130 words each) and a picture to help users differentiate between pages (see Figure 1). Pages were intentionally sparse because previous studies have demonstrated differential effects on navigation between field-dependent vs. field-independent users when multiple elements are present (Kim, 2001).

3.1.2 The navigation tools

Participants in this study used one of four different navigational tools: alphabetical, hierarchical, spatial, or spatial/hierarchical. These four different aids were described earlier in this paper (see Figures 2 through 5). The organization of the navigation aids did not reflect the linking structure of the document but only served as a representation to help the users mentally organize the document material. All page labels on all four navigation aids were linked to the corresponding page in the hyper document. As a result, the users could always navigate directly to any page from the navigation aid without having to access intermediary pages. Hence, the optimal route to a given page was always a direct selection of a particular page label from the navigation aid (see Figures 2–5).

3.1.3 The tasks

Participants were asked to complete three tasks: an information search task, a free recall task, and a distance-like ratings task.

Information Search Task: The search task began with an instruction page, followed by the navigation aid for a given condition. It consisted of ten questions presented consecutively on various aspects of fungi. Users were required to navigate the document, locate and record the phrase or sentence that answered each question.

Recall Task: The free recall task was intended to determine if there were differences between groups in how well participants could remember elements of the document content, specifically page titles. With the free recall task, participants are not cued for responses but must generate them independently. The recall task form appeared automatically after the response was submitted to the final question of the information search task. The form consisted of an instruction caption and a textbox for participants to type in the titles of pages they remembered. The instructions read, "In the text box below, type all the page titles you can remember from the "Fungi" document. When you are finished, click the "Submit" button at the bottom of the page".

Ratings Task: The ratings task was designed to reveal how participants mentally organized the structure of the document. Immediately following the recall task, participants were asked to rate 100 pairs of page titles according to their distance from or relatedness to each other. The form for the ratings task consisted of a text box with instructions at the top of the page followed by a list of page pairs on the left side of the page. On the right side, a series of buttons appeared with ratings of one to seven labeled above them. Each page contained fifteen pairs of page titles with the final page containing the remaining ten pairs. Two subgroups in each group were tested with different instructions. One group was instructed as follows "Based on a scale of 1 (lowest) to 7 (highest) rate the following A and B pairs according to the question: How related are pages A and B?". The other group was given the instructions, "Based on a scale of 1 (lowest) to 7 (highest) rate the following A and B pairs according to the question: How close are pages A and B?" Participants used the mouse to select the button that represented their chosen response for each item.

3.2 Participants

The participants were 169 undergraduate first-year psychology students (81 males and 88 females) from the University of Alberta, Edmonton, Alberta, Canada. Students participated as part of a research participation program and received credit for their participation. The students were randomly assigned to four conditions based on the navigation aid presented: Alphabetical, n = 44 (22 males and 22 females), Hierarchical n = 41 (20 males and 21 females), Spatial, n = 41 (18 males and 23 females), and Spatial/Hierarchical, n = 43 (21 males and 22 females). Participants were pretested on their Internet experience via a questionnaire. Items on the questionnaire included the frequency and duration of Internet use in a one week period, the availability of Internet access at home, and a rating of how much each participant engaged in particular Internet activities such as information searches, surfing, chat rooms, e-mail, use of search engines, copying images and the construction of a Web page. Preliminary analyses found no differences between the four groups on Internet experience.

3.3 Procedures

Each of the four groups was presented with the same test procedures. In each test session, students were randomly assigned to one of the four navigation tool groups. Students were instructed to search through the hyper document to find the answers to each of ten questions. They were also told that they would be asked to complete two tasks immediately following the information search task and that on-screen instructions would be provided for each task as they moved through the program. Each student began the test session by logging onto the program on an individual work station. After login, the students were presented with the navigation tool under which appeared the first question for the information search task. The questions would appear at the bottom of the navigation tool one at a time. When the student submitted the answer to a question, the program would proceed to the next question. After the information search task was completed, the program would proceed with the recall task and the ratings task that were described in the previous materials section.

Table 1 Means and Standard Deviations for the Average time across questions to complete the information search task for all groups

Group	M	SD	n
Alphabetical	95.42	33.48	44
Hierarchical	76.09	25.60	40
Spatial	73.92	27.25	37
Spatial/hierarchical	72.06	19.07	41

4. RESULTS

4.1 Performance results

On all the performance measures, preliminary analyses (ANOVA) indicated no differences

Table 2 Means and Standard Deviations for the Average number of pages accessed to complete the information search task for all groups

Group	M	SD	n
Alphabetical	6.87	2.48	44
Hierarchical	4.39	1.53	41
Spatial	4.91	1.7	37
Spatial/hierarchical	4.67	1.68	42

Table 3 Means and Standard Deviations for the Average number of Page Titles recalled for all groups

Group	M	SD	n
Alphabetical	9.05	3.69	44
Hierarchical	8.66	4.41	41
Spatial	9.37	4.32	41
Spatial/hierarchical	10.89	3.13	43

between genders.

4.1.1 Efficiency measures

Total task time. On the time measure, four subjects were lost due to missing data. Based on the criteria of greater than 3 standard deviations away from the mean on standardized scores, three data points were excluded as outliers. The resulting sample size for this task was n = 162. Significance for all measures was determined using a probability value of .05. The means and standards deviations for total task time for each group are shown in Table 1. To detect any differences between groups in the speed of navigation, a one-way ANOVA (Time x Condition) was conducted on total task time (n = 162). There was a significant main effect for Condition, $F(3,158) = 6.871$, $p < 0.001$. Tukey's Honestly Significant Difference (HSD) post hoc tests (Marascuilo and Serlin, 1988) were used to reveal where these differences occurred. (Alphabetical vs. Hierarchical, $p < .01$, Alphabetical vs. Spatial, $p < 0.01$ and Alphabetical vs. Spatial/hierarchical, $p < 0.001$).

The Alphabetical group performed poorly relative to the other three groups. The Spatial, Hierarchical and Spatial/Hierarchical groups perform comparably indicating that combining spatial and conceptual information did not speed up search any more than either alone.

Number of pages accessed. On the page count measure, four subjects were lost due to missing data. Based on the criteria of greater than 3 standard deviations away from the mean on standardized scores, one data point was excluded as an outlier (n = 164).

Means and standard deviations for number of pages accessed appear in Table 2. A one-way ANOVA was conducted on the mean number of pages accessed by each of the four groups (PageCount x Condition). Again, a main effect for Condition was evident, $F(3,160) = 15.084$, $p < 0.001$.Tukey's post hoc tests indicate the differences lie between the Alphabetical group and the other three groups (Alphabetical vs. Hierarchical, <0.001, Alphabetical vs. Spatial, $p < 0.001$, Alphabetical vs. Spatial/Hierarchical, $p < 0.001$). Providing organization, whether it is spatial or conceptual, contributes to a more parsimonious search.

4.1.2 Effectiveness measures

Effects on Free Recall. Recall scores were obtained for all 169 participants. There were no outliers on the recall scores. Means and standard deviations for recall appear in Table 3. A one-way ANOVA was conducted on the mean number of page titles recalled by each of the four groups (Recall x Condition). Again, a main effect for Condition was evident, $F(3,165) = 2.689$, $p < .05$. Tukey's post hoc tests indicate this result was due to a difference between the Hierarchical group and the Spatial/Hierarchical group, $p < .05$. The group with the added spatial information was more able to recall page titles than the group given only hierarchical information.

4.1.3 Proportion of correct answers

Accuracy data was available for 166 subjects. Again, based on the criteria of greater than 3 standard deviations away from the mean on standardized scores, two data points were excluded as outliers (n = 164). To detect any differences in the number of correct answers obtained by subjects in each group, a one-way ANOVA (Answer x Condition) was conducted on the proportion of correct answers. This analysis revealed a main effect for Condition, $F(3,160) = 2.664$, $p = 0.05$. Based on Tukey's HSD, this effect seems to be due to the differences between the Alphabetical group and the Spatial group (Alphabetical vs. Spatial, $p = 0.063$). However, the average scores for all four groups were high (see Table 4) indicating that the task was not difficult for most subjects. The questions used in this task were fact-based not concept-based. More challenging types of questions may have produced different levels of accuracy between groups. Evidence for

Table 4 Means and Standard Deviations for the proportion of correct answers from the information search task for all groups

Group	M	SD	n
Alphabetical	0.76	0.26	43
Hierarchical	0.84	0.15	40
Spatial	0.86	0.14	38
Spatial/hierarchical	0.85	0.14	43

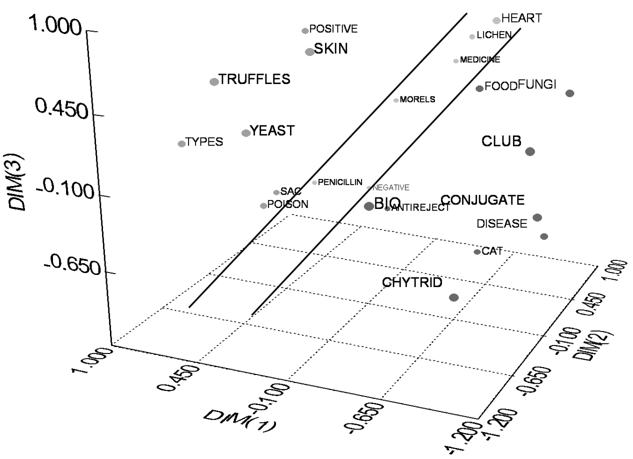

Figure 6 Three-dimensional MDS solution for the Spatial/hierarchical group

differential effects on accuracy due to question type has been documented (Leventhal *et al*. 1993).

4.2 Path Patterns: Where users go

Previous analyses on this data set investigated the relationship between the format of the navigation tool and the resultant path patterns of the users in the four groups (Boechler and Dawson, 2002). As the students completed the information search task described earlier, the program maintained a log file of all the moves the students made. The number of times students made transitions from a given page to another page was then analyzed using Multidimensional Scaling (MDS). MDS is a statistical method for revealing the underlying properties embedded within a matrix of data and displaying those properties in a visual format. In this case, the matrices of the page-transition frequencies show how frequently a move was made between one page to another for a given group of users. Based on the correlations between items in the frequency matrices, spatial coordinates were calculated and plotted in a configuration. The optimal solutions (number of dimensions) for each configuration were determined using several criteria typically used in MDS analyses (Borg and Groenen, 1997). The most common measure that is used to evaluate how well a particular configuration reproduces the observed distance matrix is the stress measure. Stress is a goodness-of-fit measure for the entire MDS representation based on the error between the observed proximities and the reproduced proximities that comprise the configuration.

There are several outcomes of this analysis that are of interest: First, the MDS configurations strongly reflected the type of information that was most salient in each navigation tool. Hence, the configuration produced by users of the alphabetical tool could be partitioned into the beginning, middle and ending of the alphabetical order of the labels. The hierarchical tool configuration could be partitioned into the three main levels of the hierarchy, the spatial configuration reflecting the clusters of the labels in that tool and the spatial/hierarchical configuration could be divided into regions that reflected both the depth and breadth of the hierarchy of information in the tree-diagram (see Figure 6). In short, users' transition choices are heavily influenced by the types of information presented in the navigation tool. Where users went was very different for each of the four navigation groups.

Second, the optimal solutions for the four groups were of different dimensions suggesting that navigation behavior are not wholly dependent on the format of the navigation tool, even when users are constrained to return to it to make all navigation decisions. If the navigation tool format completely dictated where users go, the optimal MDS solution to describe that behavior would be two dimensions for each of the groups, in essence, a reproduction of the two-dimensional configuration of each navigation tool. This is not the case. These are important findings because they suggest that other properties or characteristics of the course of navigation are mediating the relationship between the navigation tool and the resultant behavior. One possible mediating variable is the mental representation that users develop of the document.

Table 5 Correlations for average ratings between all groups.

Group	Alphabetical	Hierarchical	Spatial	Spatial/hierarchy
Alphabetical	1.000			
Hierarchical	0.864	1.000		
Spatial	0.802	0.853	1.000	
Spatial/hierarchical	0.707	0.819	0.877	1.000

4.3 Mental representation

The ratings task data provided the opportunity to investigate how mental representation is related to both performance and path patterns. Two questions of interest are: Are navigation tools impacting navigation behavior because they influence the form of users' underlying mental representations of the document or do all users develop the same representation but exhibit different behavior? If the navigation tool dictates the form of mental representation, we should see some relationships between where users go (navigation behavior – the MDS data) and the mental representations they form (the ratings data). The ratings task is based on the premise that users' estimates of the semantic distance between pages reflects their underlying mental organization of the document material.

In this study, users were asked to complete a ratings task which required them to rate the distance between 100 pairs of page titles (e.g. Lichen to Conjugation Fungi). The ratings task was administered with two sets of instructions. These instructions were designed to allow the user to interpret the task as either a spatially based or a semantically based task. Users were asked to rate the distance between pairs of pages based on either their closeness (spatial relation) or relatedness (semantic relation). The premise of this task is that users' ratings of the distances between pages will reflect the underlying representational space they have formed of the document.

Out of the 100 pairs, four pairs were omitted due to repetition or missing labels. Correlations for the average ratings between groups were high, indicating the patterns of ratings were similar across groups (see Table 5).

4.4 Instruction conditions

For each of the four groups, two-sample t-tests were conducted to detect any differences in ratings between the two instruction subgroups. Three of the four groups showed no differences between question types. Only the hierarchical group showed a significant difference between the question types, $t(190) = -2.55$, $p < .05$. Why might we see a difference in this group? Possibly, the conceptual information in the hierarchical aid, that is, the hierarchical organization of subheadings, was salient enough to the users that a distinction could be made between the notion of "closeness" versus the notion of "relatedness". With the spatial tools, for the "related" condition, it is possible the users assumed the spatial layout was a representation of the conceptual relatedness of the pages and, therefore, made no distinction between the terms "close" and "related". With the alphabetical list, either term might appear ambiguous.

4.5 The relationship between path patterns and mental representation

The MDS analyses on users' path patterns revealed that users' sequence of movements closely reflected the structure of the navigation tool. Given that the information in the navigation tool influenced where users went, the relationship between where they went (frequency of page-transition) and how they perceive pages to be related (ratings task) should be suggestive of the type of information that is the basis for their underlying mental representation. Multiple regression analyses were done to determine if frequencies (behaviour) predicted ratings (mental representation). The analyses reveal that for the two groups that contained spatial information, the spatial and spatial/hierarchical group, the page-transition frequencies predicted the users ratings of distance between pages, Spatial, $R^2 = 0.387$, $F(1, 94) = 59.438$, $p < 0.001$, Spatial/hierarchical, $R^2 = 0.141$, $F(1, 94) = 15.373$, $p < 0.001$. This suggests that the experience of moving through the document contributed to the users' mental representation of the document space. That is, their perception of the document structure was at least partially motivated by their behaviour within the document, which was in turn influenced by the navigation tool they used. This was not true for the Alphabetical and Hierarchical groups. One possible account for this result is that, spatial information may facilitate the integration of knowledge obtained from two separate sources: the navigation tool itself and the experience of moving through the document. If so, users given spatial cues have the advantage of only having to access a single representation in memory rather than having to mentally combine information from multiple sources.

5. DISCUSSION

5.1 Performance

Even in a small, constrained hyper document, we see differences in performance based on the information provided through the navigation tools. Generally, providing alphabetical information alone in a navigation tool resulted in poorer user performance.

Viewing the two efficiency measures separately, for speed of navigation, as measured by time on task, either spatial or hierarchical information or a combination of both, lessens the time it takes to complete the information task. For economy of search, as measured by the number of pages accessed, spatial and/or hierarchical information seem to contribute to a more parsimonious search, that is, where users access less pages to locate target information. For both measures, the post hoc analysis of the individual groups has produced a rather counterintuitive result. Although both spatial and conceptual information is important, combining spatial and conceptual information in the combination used in this study does not produce faster or more economical search.

Regarding effectiveness measures, alphabetical information alone produces poor search accuracy relative to the spatial group. The spatial, hierarchical and spatial/hierarchical groups perform comparably on search accuracy. However, spatial cues added to hierarchical information does impact users' ability to recall page titles from the document. The spatial/hierarchical group retrieved significantly more titles in the free recall task than the hierarchical group.

In relation to previous research, the results of the effectiveness measures are inconsistent with McDonald and Stevenson's (1999) who found no difference on recall measures between a conceptual versus spatial map. This is possibly due to the confounding of spatial and conceptual information, which was addressed in this paper, but could also be attributed to the structural differences in the navigation aids themselves. For example, both McDonald and Stevenson's (1999) navigation tools included link designations whereas the spatial map in this study did not. Also, McDonald and Stevenson (1999) used localized spatial maps instead of global spatial maps. Potentially, the impact of spatial information on effectiveness measures may be less crucial when the users are viewing only a portion of the whole document structure rather than the entire document structure. This is an issue that needs to be addressed in future research.

Clearly, structural aspects of a hyper document may affect the usefulness of a given navigation tool: document size, local versus global navigation tools, the types of information provided or the linking structure. These structural effects are important to consider in the context of different navigational goals. Users begin navigating a document with an overall goal in mind. They could be browsing with no specific target in mind, searching for a particular piece of information that they have not located before, or reconstructing a previous search. The task demands of the overall goal determine the sub goals that users must set for themselves. These sub goals are not end states but are outcomes of more process-oriented strategies such as moving quickly, opening the fewest pages or remembering a page or subset of pages.

The results of the performance analyses suggest that different kinds of information in a navigation tool may support different sub goals. For example, the goal of remembering the basic elements of the document is enhanced by hierarchical information combined with spatial information over hierarchical information alone. Hence, different types of information in a navigation aid may provide support for only some of the sub goals involved in the course of navigating a document. Subsequently, the match between the goals of the user and the type of support the navigation tool was designed to provide would be particularly relevant. This would be true for both intermediate process goals as well as for overarching goals.

Given the findings of this analysis, it is apparent that the appropriate question is not whether a spatial versus conceptual navigation tool is better, but rather which combinations of conceptual and spatial cues provide the best support for a particular set of goals. Identifying the types of cues that support intermediate processes such as moving quickly, accessing the fewest pages, recalling basic elements and accurately targeting specific information needs to be undertaken within the context of different hypertext structures across the time course of navigation.

5.2 Mental representation

Based on the distance ratings, high correlations between the four groups' average ratings indicate the patterns of ratings were comparable across groups suggesting all groups formed a similar mental representation.

At the start of the tasks, the users are first exposed to the navigation tool. The assumption is that, initially, the navigation tool prompts users to form a hypothetical organization for the material. As users move through the document, their navigation experiences potentially confirm and facilitate further development of these representations. Although the mental representations as indicated by the ratings are similar across groups, the page-transition frequencies (where users went) indicate that navigation behaviours are differentially associated with the structure of the navigation tool. For tools with spatial cues (spatial and spatial/hierarchical), the mental representation and the path patterns of users are related. Users' navigation behavior predict the mental representations they have formed by the completion of the tasks. For the non-spatial tools (alphabetical and hierarchical), the relationship between mental representation and path patterns does not hold. Users' navigation behavior do not predict the mental representations they have formed by the completion of the tasks.

5.3 Relationships between performance and mental representation

If all groups form comparable mental representations of the document material, why would the alphabetical group perform poorly relative to the other three groups? A possible explanation is that, for the alphabetical and hierarchical groups, two representations develop; a representation of the navigation tool itself and a representation of the content of the document. For the hierarchical list users, the presence of hierarchical information provides conceptual information related to the information conveyed by the two spatial tools, possibly allowing for some merging of the two representations. Hierarchical organization could be suggestive of a tree-like organization with super-ordinate, basic and subordinate levels. Hence, the hierarchical group performs comparably to the two groups with spatial cues. For alphabetical users, the absence of information that organizes the material in a meaningful way leaves the user with separate unrelated notions of the document space, one based on the alphabetical organization of the content list and the other based on a relational organization constructed through the experience of navigation.

If this is the case, then discrepancies in performance would not be due to the development of different mental representations but may instead be due to difficulties in consolidating multiple, unrelated forms of information (e.g. the alphabetical list has no relation to the semantic-relatedness of pages) into a single, cohesive representation. This suggests that performance is enhanced when the information in the navigation tool corresponds to the conceptual organization of the material and that conceptual relationships can be conveyed via spatial cues or hierarchical information.

5.4 Relationships between path patterns and mental representations

The regression analyses on the ratings data indicate that where users go predicts the form of the mental representation for the two groups that contain spatial cues. The navigation tool with hierarchical information alone does not produce this relationship nor does the alphabetical tool. This implies that, in the ongoing links between the navigation tool, path patterns and representation there is something unique about spatial information. It is possible that certain spatial cues provide an initial hypothetical organization of the material in a form that facilitates the integration of further information, that is, relational information gathered through traversal of the document. This results in a final integrated representation of information from all three sources.

The analysis of the ratings data backs up the complexity of the relationships between different aspects of the navigation experience as suggested by the MDS analysis. There appears to be a continuous relationship between elements of the early navigation experience and variables that appear later on. However, this does not seem to be a one-to-one correspondence between individual variables but rather a cumulative, sequential relationship between numerous variables.

This study is an investigation into the cognitive processes involved in hypertext use with a particular focus on mental representation which requires the modification of established psychological methodologies to the particular environment of hypertext. The ratings task was employed to tap into user mental representations of the document space. The usefulness of the ratings data relies on the assumption that the ratings are a reasonable reflection of that underlying mental organization of the material. Additional studies are needed to ascertain if this is a valid assumption.

The format of the navigation tools in this study represents only one option for presenting spatial information. Additional studies using various spatial contexts are required to fully comprehend the role of spatial processing in a hypertext environment.

6. CONCLUSION

The results of this study highlight three points regarding the effects of navigation tool content: First, navigation tools containing spatial and hierarchical information enhance performance over an alphabetically ordered tool whether these types of information appear in isolation or combination. However, combining spatial and hierarchical information does not produce enhanced performance over either alone.

Second, the MDS analysis shows that each group's pattern is different not only in shape but also in the degree to which it reflects various dimensions of each navigation tool. Where users go is substantially influenced by the information in the navigation tool. The path patterns of a given group reflect the predominant type of information within that particular navigation tool.

Third, even though users in all four groups produced comparable ratings on the ratings task, only the two groups who were given spatial cues exhibited navigation behavior that predicted their subsequent mental representations of the document. For users given spatial cues, navigation tool information impacts users' perceptions of the document space in an indirect fashion, through the tool itself but also via the navigation experience that the tool induces.

Although performance differences are not evident for users given spatial cues, relationships do exist between the navigation tool, the course of navigation itself and the mental representations that users form of the hyper document. It is a reasonable conjecture that creating or maintaining this type of coherence across different aspects of the navigation experience may help reduce cognitive overhead and allow users to focus more closely on the material within the document. Future research is needed to understand specifically how spatial cues might mediate such relationships and how these relationships might be used to alleviate cognitive overhead.

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