Individual differences and navigation in hypermedia

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ABSTRACT

This study derives from two important observations. First, that navigation in hypermedia is a difficult task, and second, that individual cognitive differences play a role in how well users are able to efficiently use computer systems.

We found that of the cognitive abilities tested in our study, only spatial ability could be related to the time spent in completing a set of tasks in a large, hypermedia, information structure. We furthermore found that it was only certain aspects of spatial ability which were related to the ability navigate in hypermedia, namely those related to solving spatial problems mentally rather than solving spatial problems in the physical world.

We discuss how our findings may influence the design of hypermedia systems.

Keywords

Hypermedia, spatial ability, human-computer interaction

INTRODUCTION

This study derives from two important observations. First, that navigation in hypermedia is a difficult task, and second, that individual differences play a role in how well individual users are able to navigate in other circumstances.

Navigation in large hypermedia information structures has long been recognised as a difficult and demanding task. The expression 'lost in hyperspace', (Conklin, 1987), describes what happens when users loose track of where they are and where to go next in the hypertext (see for example (Nielsen, 1990)). Navigation in hypermedia structures is similar but not equal to information retrieval in general.

Egan, (1988), shows that the best performer will solve tasks 20 times as quickly as the worst performer. This should be compared to "normal" tasks where a good performer does about twice as good as the worst. There are some studies on information retrieval behaviour that try to pinpoint the reasons why there are so large individual differences in terms of time spent and number of errors made. Borgman, (1989), provides an overview of such characteristics which have shown to be related to information retrieval behaviour. In most studies, we find that the users *previous experience* of the target system or computers in general, is among the most important factors that influence the users performance (Elkerton and Williges, 1984; Benyon and Murray, 1993). In addition, Egan identifies a cluster of factors which he names *technical aptitude* that is correlated with search behaviour, (1988). Technical aptitude includes spatial and reasoning abilities and background (as coursework in math and science).

Other factors mentioned by Borgman are *age*, *sex* and *personality*. Increasing age can be correlated with number of errors in information retrieval tasks (Borgman citing Greene at al. 1986). Sex is not related when experience and coursework are controlled, but as more males enter math and science education, they tend to have higher technical aptitude. Finally, Borgman shows that personality traits accounts for a large proportion of the choice of academic orientation which in turn is related to technical aptitude.

The relationships between navigation in hypermedia and the users cognitive abilities, is not clear. As indicated by the technical aptitude factor, it seems as if *spatial ability* is one crucial factor. This can be examplified with Vicente and Williges study where they found that spatial ability could be linked with whether users get lost in a hierarchical file system (1988). Also, in a study by Benyon and Murray (1993) it was found that spatial ability determined how well users performed with different interfaces to a database system. Users with low spatial ability performed better with an aided-navigation interface with a constrained dialogue, while users with high ability made better use of a non-aided navigation interface with a flexible command-based dialogue.

Spatial ability is a cognitive characteristic which offers a measure of a user's ability to conceptualise the spatial relationships between objects. It is closely allied to the notion of a cognitive map (Neisser 1976), and (following (Vicente et al. 1987) and (Vicente and Williges 1988)), may also be related to a user's ability to navigate through a complex space.

Attempts to isolate individual cognitive differences are generally based around the production of various aptitude tests and other devices designed to isolate specific factors (Dillon and Schmeck 1983, Dillon 1985). Cognitive abilities, or cognitive skills, as spatial ability, seek to describe the methods by which humans process information (van der Veer 1994).

It should be noted that spatial ability has been measured with different tests in the different studies. It is not clear that it is the same cognitive activity that is discussed in the different cases.

So, in summary, there are large differences between individual users and their ability to search for information, and a number of individual characteristics can potentially explain these huge differences. As information retrieval systems cannot be such that they only direct themselves to an exclusive population (as pointed out by Egan, 1988), there might be reasons to design the system so that it meets the needs and abilities of their users rather than the other way around. In particular, this becomes crucial if the related individual characteristics are more resistant to change than others (as suggested by van der Veer, (1989)).

Hypothesis

The present study investigates the relation between cognitive abilities, in particular spatial ability, and ability to navigate in hypermedia. Our hypothesis is that people with a low spatial ability have more difficulties in navigating to and interpreting information in a hyperspace.

The hypothesis stems from an observation in one of our previous studies (Bladh and Höök 1995) on a hypermedia documentation system, where we found that our user group could be divided into two. One found the graphs provided by the system helpful as tools for navigating to documents. The other group was annoyed by the graphs, and would have preferred other ways to navigate and search for information.

In this study, we tested the subjects cognitive abilities, and then made them solve six tasks with the hypermedia system. By choosing the navigational tasks so that they included navigation between several ”pages” of information in order to find the requested information, we provoked navigation. The cognitive tests included tests of verbal ability and logical-inductive ability (apart from the tests of spatial ability and perceptual-analytic ability) in order to exclude the possibility that it was general intelligence that was related to the subjects navigational skills.

Characteristics of the hypermedia tool studied

Before describing the study, we need to provide a short introduction to the hypermedia tool studied. The tool was an on-line manual implemented in FrameMaker™. The domain described in the tool was an object-oriented software development method, named SDP, consisting of *processes* (in which project tasks were specified) and *object types* (in which the results were documented). The users were software developers, designers, project managers, etc., involved in developing large-scale telecommunications systems.

A schematic picture of the structure of the on-line manual can be found in **figure a**. The *process structure* and the *object hierarchy* function as maps to the two main structures in the domain: the process structure and the object type structure. From the process structure it is possible to reach graphical descriptions (or views) of each process, the *process graphs*. From the process graphs in turn, textual descriptions of the processes can be reached. From the object type hierarchy the *object type graphs* can be reached, and from those the textual descriptions of each object type can be reached.

So, in order to get to a textual description of a process or object type, it is necessary to navigate via a set of graphs until the bottom of the hierarchy is reached - only there a textual description will be found.

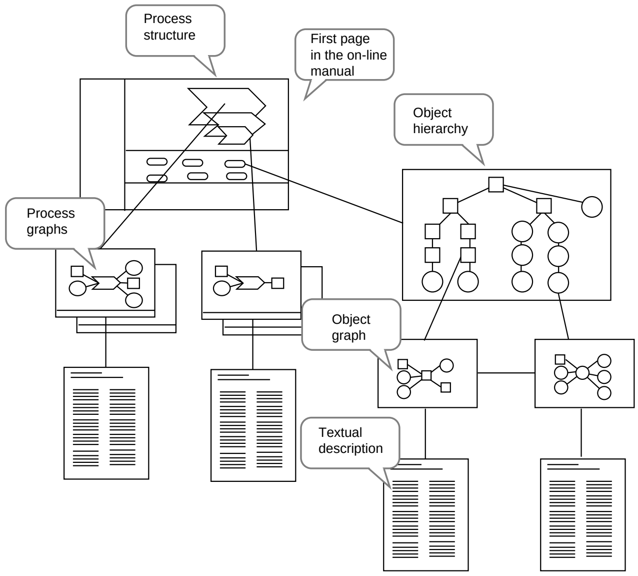

Figure A. The structure of the existing on-line manual.

There are two aspects of the domain which are spatial in their nature. The domain itself is an abstract structure with relations between processes and object types. Second, the on-line manual is, as said above, structured in a set of documents with specified relations between the documents. The structure of the on-line manual is only partly based on the structure of the domain. So therefore the user has to learn two structures: the manual structure and the domain structure of processes and object types.

STUDY

Subjects

There were 23 subjects in the experiment, 19 male and 4 female, all employed at Ericsson Utvecklings AB or Ericsson. The subjects were in a range of 20 - 55 years old (m=34 years). All had some computer training, but not all had gone through higher academical training (18 had higher academic training and 5 had no academic training). All had recently gone through a four day course on the SDP method itself, but they had received little or no training on how to use the on-line manual.

Material and procedure

The experiment was divided into three parts. First, the subjects cognitive abilities were tested, followed by a questionnaire about their background (education, age, etc.) and finally, they completed six navigational tasks (while being video-taped) in the on-line manual. After solving each of the navigational tasks, the subjects answered a set of queries on how difficult they had perceived it to be to find the information, etc.

Cognitive abilities

The cognitive abilities were tested using a subset of the Düremann-Sälde (Psykologiförlaget 1971) test battery:

- verbal ability (synonym test).
- logical-inductive ability (classification of images).
- perceptual analysis (drawing imitation of images).
- spatial , tested through three different tests:
    - rotation of images: the subject choose the images that are identical with the image in the task.
    - identification of left or right hand in pictures of hands that were turned in different ways,
    - a blocks test (Koh's block test): the subject makes a pattern using blocks according to a given pattern.

Navigational tasks
Finally the subjects were asked to complete a set of six information seeking tasks and after each to evaluate their own performance, as whether they thought they had found the correct answer and whether they found it the most efficient way. The six tasks to be solved with the on-line manual and the subjects evaluation of their own performance took approximately 1/2 - 1 hour per subject. The information seeking tasks were designed to have the following properties:

- We used questions that we had collected in our previous studies from users actually working with the method and entering the on-line manual to find particular pieces of information.
- We designed two tasks, number 2 and 6, so that they asked for the same information concerning two different processes in the method - our hypothesis was that the second time around, users would more easily find the right information if they had built a good mental map of the information space.
- One task, number 5, could only be solved by looking in the textual parts of the on-line manual. That to see when the subjects made the decision to use that part of the on-line manual (immediately or after hesitation) and once in this part of the on-line manual, how they searched for information in the text.
- A criterion for some of the tasks were that they should force the subjects to navigate between the different graphs, that to see if and how the subjects used a mental model of the information space.

RESULTS

Patterns of cognitive abilities
A factor analysis of the results of the six cognitive tests revealed three underlying factors, with two tests with high loading in each factor, see **table a**. Factor 1, with high loading on figure drawing test and the block test, factor 2 with high loading on the tests of synonyms and the classification of images, and factor 3 with high loading on the tests on rotation of images and of hand identification.

The factor analysis groups the tests in a different way than in the test materials. Note especially that the blocks test is more strongly associated with the figure drawing test than with the other two spatial tests.

This could indicate that there is a difference between the manipulation of spatial information in the mind and the acting in the world, even if both from a superficial point of view seem to concern the same kind of information processing.

Cognitive test	Factor 1	Factor 2	Factor 3
Synonym test	.164	.843	.046
Classification of images	.284	.810	-.041
Image drawing	.958	.071	-.071
Rotation of images	.227	-.393	.654
Rotated hands	.00001	.067	.940
The block’s test	.792	-.001	.376

Table A. A factor analysis of the cognitive tests.

Cognitive ability and task completion time
The only correlation we found was that the completion time correlates with the spatial ability as measured with the two tests in factor 3, ($r = .56$, $p < .005$), see **figure b**. (To be able to study the correlation between the subjects' abilities in the different factors and their task performance, we simply added the stanine points of the test scores on the two tests with the highest loading on the different factors). No other correlation's achieved significance. The correlation between the completion time and the blocks test was for instance only $r = .04$.

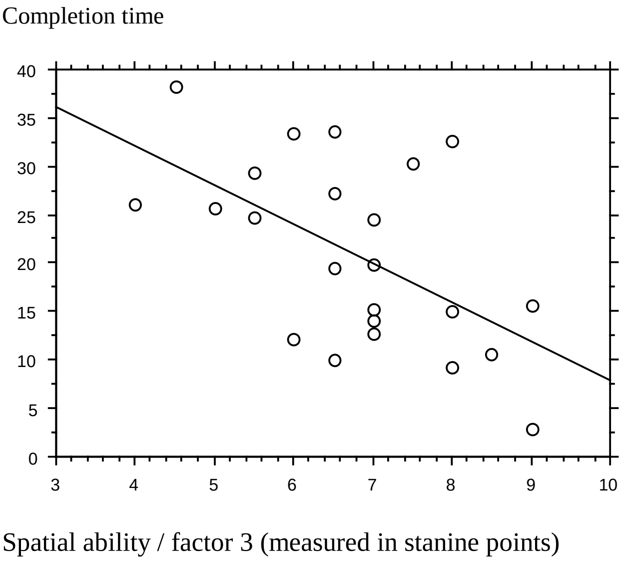

Figure B. The correlation between completion time and spatial ability.

The difference between the best and worse performance in our test is 19:1, i.e. the best subject solved the tasks 19 times as fast as the subject who solved them slowest.

If we divide the subjects into two categories, those with high ability with respect to factor 3 and those with low ability, the result becomes even more evident. The group is divided into two halves of (almost) equal size: the high ability group, consisting of 12 subjects has an average stanine-score above 6.5 points, while the low ability group, consisting of 11 subjects lies below 6.5 points. In

table b, we see the results: the low ability group took about 25 minutes in average to complete the tasks, while the high ability group completed the tasks in 17 minutes. There was no significant difference in number of clicks (i.e. moves between pages of information or graphs) between the two groups. It seems as though the low-ability subjects spend more time in studying each page.

Spatial ability (factor 3)	Time	Clicks
High (12 subjects)	16.94	49.67
Low (11 subjects)	25.47	54.09

Table B. Total time and total number of clicks done in order to complete the six navigation tasks for the low and high ability groups on factor 3.

Correlation with map-reading ability

In our questionnaire, we asked the subjects to estimate their own ability to read and use maps and their ”sense of location”. Streeter and Vitello, (1986), found that subjects self-estimated ability to read and use maps was strongly correlated with their actual map-reading ability. It is also the case that those who tend to like maps will use maps more often and thereby improve their performance. So, our subjects own estimate of the map-reading ability can be taken as a good measure of their actual (map-reading) ability.

We found that the subjects map-reading ability was correlated with factor 1 (the ”external” spatial ability) in our cognitive tests, r=.42, P<.05, while there was no correlation between map-reading ability and factor 3 (the ”mental” spatial ability).

Again, this would indicate that there is a difference between spatial ability for solving problems in the world (where groundedness is possible) and spatial ability for extracting abstract structures from non-grounded domains. This may also imply that we can help one group of users to improve their performance through providing maps of the information structure. This group of users are those who are low on ”mental” spatial ability, but high on ”external” spatial ability.

Confidence in answers

In **figure c** we compare the mean number of clicks the subjects took in order to complete the tasks with the optimal, lowest, number of clicks by which someone could have found the answer (as computed by us who knew where the answers were). As we can see, the amount of ”unnecessary” clicking is not so bad for some of the tasks. Task 3 and 4 stand out from the rest of the tasks.

Task 3 required that the subject studied at least two different graphs and computed the answer from relating the two graphs. Most subjects studied three or more graphs (which provided different viewpoints of the same graphical relations) and looked at each graph several times in order to make sure that they had understood the relations correctly. (It should be noted that each individual graph was very simple).

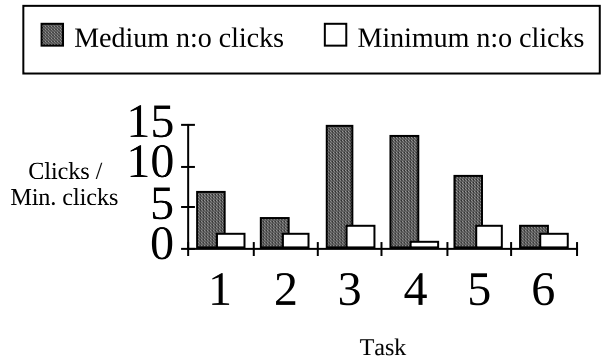

Figure C. Medium number of clicks performed by the subjects compared with minimum number of clicks possible for each of the six navigational tasks.

The second task which seemed to take a lot of unnecessary clicking is task 4 which was a search task in which the users were required to look through several nodes in order to make sure that they had in fact found the correct answer. The minimum number of clicks for this task was based on the fact that we knew what the answer was and we did not need to make sure that there was any information that would contradict this conclusion.

So, in summary, the users did not perform too badly in terms of visiting too many nodes in the information space.

It seems as though the hypermedia tool raises the expectation of finding the information "just a few click away". As soon as the subjects have to perform more than a few clicks, they assume that they have gone wrong somewhere in the hypertool. As we can see in **table c**, the subjects tend to be more unsure of whether they have actually found the correct answer when they have to study several pages of information (as in task 3 and 4) in order to find the answer: for task 3 eight subjects had a low confidence in whether they thought they had found the answer, and for task 4 ten subjects had a low confidence in having found the correct answer.

Tasks/ Confidence	1	2	3	4	5	6
0-2 (low)	1	5	8	10	3	3
3-5 (high)	22	18	15	12	18	19

Table C. The number of subjects who had a self-assessed low confidence (0-2) or high confidence (3-5) in having found the correct answer to the six different tasks.

Another tendency, which we cannot verify in this study, but that should be dealt with in subsequent studies, is a relation between being unsure about whether the answer is correct, when the answer was to be found in a graph (or a combination of several graphs). Our subjects sometimes stated that they would have liked to see the answer in text to make sure that the answer was correct. This tendency can explain why they did so many clicks for task 5 (where the answer could only be found in the text), and still had a high confidence in having found the correct answer. It can also explain why they were so unsure about whether the answer was correct for task 3 and 4 where the answer had to be computed from different graphs and could not be found in the test.

This confirms with the results of Hare et al. (1995) who showed that users did study figures, but when they were asked to give a definitive answer, they would rather turn to a textual description than to extract the answer from a picture.

DISCUSSION

Our hypothesis that navigation in the on-line manual could be correlated with spatial ability turned out to be correct. There we no correlation's with other cognitive abilities.

The results with the two factors, factor 1 and factor 3, as different aspects of spatial ability should be verified in other studies, but should they hold also under closer scrutiny, this could not only have theoretical, but also practical consequences.

A practical consequence can be that we should be supporting users of hypermedia with low spatial ability with external aids that transforms an internal task into an external one - sometime we discuss below. In fact, as pointed out by Vicente and Williges (1988), such aids might also help users with high spatial ability by decreasing their cognitive load.

On the theoretical side we have argued that a distinction could, and perhaps should, be made between spatial tasks that are performed as bodily actions in the world and those that take place solely in the mind. Our analysis of the subjects' response pattern on the cognitive abilities test gave some support for that notion. Further support was gained from the fact that the only cognitive abilities tests that correlated with the performance in using the help system was those that seemed to measure internal spatial tasks. The fact that the ”external” spatial ability was correlated with the subjects self-estimated ability to read maps but not correlated with the mental spatial ability, reinforces the messages that the two abilities are different.

Yet another result is that hypertools raise the expectations of finding information just a few clicks away.

Finally, we also found some interesting aspects of graphical versus textual presentation of information. It seemed as though textual presentation was considered to be a more reliable source of information, or that the subjects found it hard to interpret the graphs provided in the on-line manual. Also, compiling an answer from several graphs seemed to be a difficult task - even though each graph in itself was fairly simple.

IMPLICATIONS FOR INTERFACE DESIGN

Since spatial ability is resistant to training, it is necessary that we find ways to improve the interfaces instead. Then users with low spatial ability will be enabled to better solve their real tasks. The are numerous ways by which we can improve the interfaces to hypermedia.

Firstly, it has been pointed out by, among others, Vassileva that search in a hyperspace should always be complemented by the possibility to pose search questions (Vassileva, 1995, Höök et al., 1996). Our subjects sometimes said that they would have wanted to see the information written in text, but since it was so hard to navigate to a text and then find the relevant information within those text pages, they hardly ever were able to find the right information. Provided with search questions, they would (presumably) have performed much better in retrieving textual descriptions. This would furthermore have avoided the pictorial characteristics of the interface altogether, and might therefore be better suited for some users who disliked the graphs.

Secondly, hypermedia is sometimes provided together with a navigation map or dialogue history which allows the user to trace where they have been previously, or at least they are provided with an overview of the information space. This would have helped the users to know where in the information space they were currently at. On the other hand, it is not clear that all users with low spatial ability would be helped by such maps. We know that there are many users with low map-reading skills (Streeter and Vitello, 1986). Still, since map-reading skill was correlated with factor 1 and not with factor 3, we could achieve a better interface for those with high ability in factor 1 but not so high ability in factor 3.

Thirdly, it has been shown that users with low spatial ability are helped by system which achieves *visual momentum* (Vicente and Williges, 1988). Visual momentum is achieved when parts of the previous state of the interface is visible after the user has made an action at the interface. Vicente and Williges used a hierarchical file system with folders and files in folders in their studies. When the user attempts to open a folder, the content of the folder can be shown in a new window, perhaps completely covering the set of files and folders on the higher level. A way to achieve visual momentum, on the other hand, would be by inserting the file names in the folder indented inside the list of files and folders on the higher level. The previous state of the file system is thereby still visible to the user after the new action has been taken.

The reason that visual momentum helps users with low spatial ability, is that we move from requiring that the users recall where they are and where they should go next in the hyperspace, to recognising the structure and the links and basing their decisions on that recognition. So the interface provides memory support. Or phrased in terms of the results of this study: the mental spatial task is transformed into a external spatial task.

In a hypermedia system, it is harder to achieve visual momentum in a simple way since the whole idea is to move between whole pages of text (or graphics). Still, a dialogue history (either in map form or as a list of the names of visited nodes as in Netscape - a WWW browser) could be an improvement.

It should be observed that off loading the mental load of spatial cognition, might help both those users with low and high spatial ability, as discussed by (Vicente and Williges, 1988). It is not clear exactly what is improved by providing the kind of aids as outlined above.

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REFERENCES

Allen, B. (1992) *Cognitive Differences in End User Searching of a CD-ROM Index*, 15th Annual International SIGIR'92, ACM, Denmark.

Benyon, David R., and Murray, Dianne M. (1993) *Developing Adaptive Systems to Fit Individual Aptitudes*, Proceedings of Intelligent User Interfaces'93, Florida, ACM Press.

Bladh, Malin, and Höök, Kristina (1995). Satisfying User Needs Through a Combination of Interface Design Techniques, In: K. Nordby, P.H. Helmersen, D.J. Gilmore and S.A. Arnesen (eds.), *Human-Computer Interaction INTERACT'95*, Chapman & Hall, Oxford, 1995.

Borgman, Christine L. (1989). All Users of Information Retrieval Systems are not Created Equal: An exploration into individual differences, *Information Processing & Management*, Vol. 25, No. 3, pp. 237-251.

Conklin, J. (1987). Hypertext: An Introduction and Survey, *IEEE Computer*, 20:17-41.

Dahlbäck, Nils, Höök, Kristina and Sjölinder, Marie (1996). *Spatial Cognition in the Mind and in the World: The case of hypermedia navigation*, The Eigtheenth Annual Meeting of the Cognitive Science Society, CogSci'96, University of California, San Diego, July.

Dillon, R. F. (1985). *Individual Differences in Cognition, Volume 2* Academic Press, London.

Dillon, R. F. and Schmeck, R. R. (1983). *Individual Differences in Cognition Volume 1* Academic Press, London

Egan, D. (1988). Individual Differences, In M. Helander (ed.) *Handbook of Human-Computer Interaction.* Elsvier Science,

Elkerton, J, and Williges, R. C. (1984). Information Retrieval Strategies in a File-Search Environment, *Human Factors* **26** (2), pp. 171 - 184.

Espinoza, Fredrik and Höök, Kristina, (1996). *A WWW Interface to an Adaptive Hypermedia System*, Conference on Practical Application of Agent Methodology (PAAM), London, April.

Greene, S. L., Gomez, L. M., and Devlin, S. J. (1986). A Cognitive Analysis of Database Query Production, *Proceedings of the Human Factors Society*, pp. 9 - 13.

Hare, M., Doubleday, A., Ryan, M., and Bennett, I. (1995). Intelligent Presentation of Information Retrieval from Heterogenous Multimedia Databases, In John Lee (ed.) *Proceedings of the First International Workshop on Intelligence and Multimodality in Multimedia Interfaces: Research and Applications*, Edinburgh.

Höök, Kristina, Karlgren, Jussi, Wærn, Annika, Dahlbäck, Nils, Jansson, Carl-Gustaf, Karlgren, Klas and Lemaire, Benoit (1996, in press). A Glass Box Approach to Adaptive Hypermedia, *Journal of User Modelling and User Adaptive Interaction*, UMUAI 6, in press.

Karlgren, Klas (1992) *Orientering i Hypermedia*, SISU report number 8, SISU, Stockholm, Sweden.

Neisser, U. (1976). Cognition and Reality, W. H. Freeman and Company, San Francisco.

Nielsen, Jacob (1990). *The art of navigating through hypertext*, Communications of the ACM 33(3):296-310.

Psykologiförlaget (1971) Manual till DS-batteriet, Psykologiförlaget AB, Stockholm.

Streeter, Lynn A. and Vitello, Diane (1986). *A Profile of Drivers' Map-Reading Abilities*, Humans Factors, 28(2).

Vassileva, Julita (1995). Ensuring a Task-based Individualized Context for Information Retreival from Hypermedia Information Systems for Hospitals, in IJCAI'95 Workshop on Intelligent Multimedia Information Retrieval.

van der Veer, Gerrit C. (1989). *Individual differences and the user interface*. Ergonomics, 32, pp. 1431-1449.

van der Veer, Gerrit C. (1994). *Mental models of computer systems: visual languages in the mind.* In: M.J. Tauber, D.E. Mahling, F. Arefi (eds.) Cognitive aspects of visual languages and visual interfaces. Elsevier Science B.V., Amsterdam 3-40.

Vicente, K.J., Hayes, B.C. and Williges, R.C. (1987). Assaying and isolating individual differences in searching a hierarchical file system, *Human Factors*, 29(3), 349-359.

Vicente K. J. and Williges, R. C. (1988). Accommodating individual differences in searching a hierarchical file system, *International Journal of man Machine Studies*, 29 647 - 668