Individual Differences and Navigation in Hypermedia

Kristina Höök†, Marie Sjölinder‡ and Nils Dahlbäck¥

† SICS, Box 1263, S-164 28 Kista, Sweden , kia@sics.se, http://www.sics.se/~kia

‡ DSV, Stockholm University/ KTH, Electrum 230, s-164 40 Kista, Sweden

¥ IDA, Linköping University, S-581 83 Linköping, Sweden, nda@ida.liu.se, http://www.ida.liu.se/~nda

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.

1 Introduction

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 make use of computer systems. These two observations lead us to perform a study of the correlation between the individual users cognitive abilities and their ability to navigate in hypermedia.

Navigation is a difficult cognitive activity

Navigation in large hypermedia information structures has long been recognised as a difficult and demanding task. The expression 'lost in hyperspace' 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 is a concept which has been studied with respect to such things as Polynesian sailors crossing the sea (for an overview, see (Hutchins, 1994)) and finding ones way around cities (Streeter and Vitello 1985, Streeter et al. 1985, Streeter and Vitello 1986, Höök and Karlgren 1991). In the world of interaction with computer systems, navigational issues are part of several different aspects of the user interface, and there have been several studies of those aspects:

- in the progression of the dialogue (be it via commands or menus or some other interaction style) in interacting with a database system, as studied by (Jennings, Benyon and Murray, 1991),
- in search for information in databases and considering the users conceptual model of the information found as studied by (e.g. Reisner, 1980, Karlgren, 1992),
- in interaction styles for access of multidimensional sound spaces (Eaglestone and Vertegaal 1994).

In general, is recognised that navigation is a complex activity which substantially adds to the users cognitive load.

Individual differences influence navigation

Individual differences appear to have a big impact on human-computer interaction in general (Egan 1988). When designing tools for navigation in hypermedia, individual differences may be one crucial factor that a system should accommodate to. It has been suggested, (van der Veer 1989), that some characteristics of people are more resistant to change than others. In particular, cognitive and personality traits are most resistant to change, (Carroll 1983). 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, seek to describe the methods by which humans process information (van der Veer 1994).

The relationships between navigation in hypermedia and the users cognitive abilities, is not clear. There are studies that show that previous experience is the most important factor for determining the ability to navigate in hypermedia (Karlgren 1992), while other claim that search tactics are influenced by, among other, spatial scanning abilities (Allen 1992). For other kinds of human-computer interaction situation, *spatial ability* seem to one crucial factor. For example, Vicente and Williges found that spatial ability could be linked with whether users get lost in a hierarchical file system (1988). Benyon and Murray (1993) found that spatial ability determined how well users performed with different interfaces to a database system. Users with low spatial ability performed better with a 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.

Conceptual issues

While there are similarities between navigation in the real world and navigation in the virtual world of hypermedia, there are also at least one important difference. In the former case people live in the world and they can move physically in it, whereas in the latter the *groundedness* is more limited, i.e. the possibility to interpret actions and objects in terms of real physical actions or objects. The question then arises whether a consequence of these differences is that different cognitive abilities are crucial for the successful task fulfilment in these different 'worlds'. In the present study we make a first attempt towards the answering of this question by including a fairly large number of different cognitive tests of visual, spatial and other cognitive abilities, making it

possible to analyse the contributions of different aspects of visio-spatial cognition to the task of navigating in hypermedia.

The present study

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 (described in section two), where we found that our user group could be divided into two groups. 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 our study (described in section three), 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 which was related to the subjects navigational skills.

2 Characteristics of the hypermedia tool studied

The hypermedia tool used as the target domain in this study contains information about an object-oriented Software Development Method (SDP). The method consists of *processes* which are activities done during the project phases, and *objects* which are specifications, pieces of code, etc. produced as a result of the method. Objects are the input and output of processes. In addition, objects are related to other objects with defined relationships as "is-a", "part-of", etc. Finally, processes are temporally related so that one process comes before another, is part of another process, or should be run in parallel. Each process and object is documented in fairly big documents: 6 - 20 pages. As can be understood from this, the user is confronted with is a complex and large information space.

In order to aid the users, there is an on-line manual structured as a hypermedia system. In the manual, there is no other means of finding a particular document, but through clicking in several graphs until the document is reached. A schematic picture of the structure of the on-line manual can be found in figure 1. The *process structure* and the *object hierarchy* function as maps to the two main structure in the domain: the process structure and the object structure. From the process structure it is possible to reach descriptions of each process, the *process graphs*. From the process graphs in turn, textual descriptions of each process can be reached. From the object hierarchy the *object graphs* can be reached, and from those the textual descriptions of each object .

So, in order to get to a textual description of a process or object, it is necessary to navigate via a set of graphs until the desired process or object graph is reached. From there, and only from there, is it possible to get to the textual description.

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 objects. 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 objects.
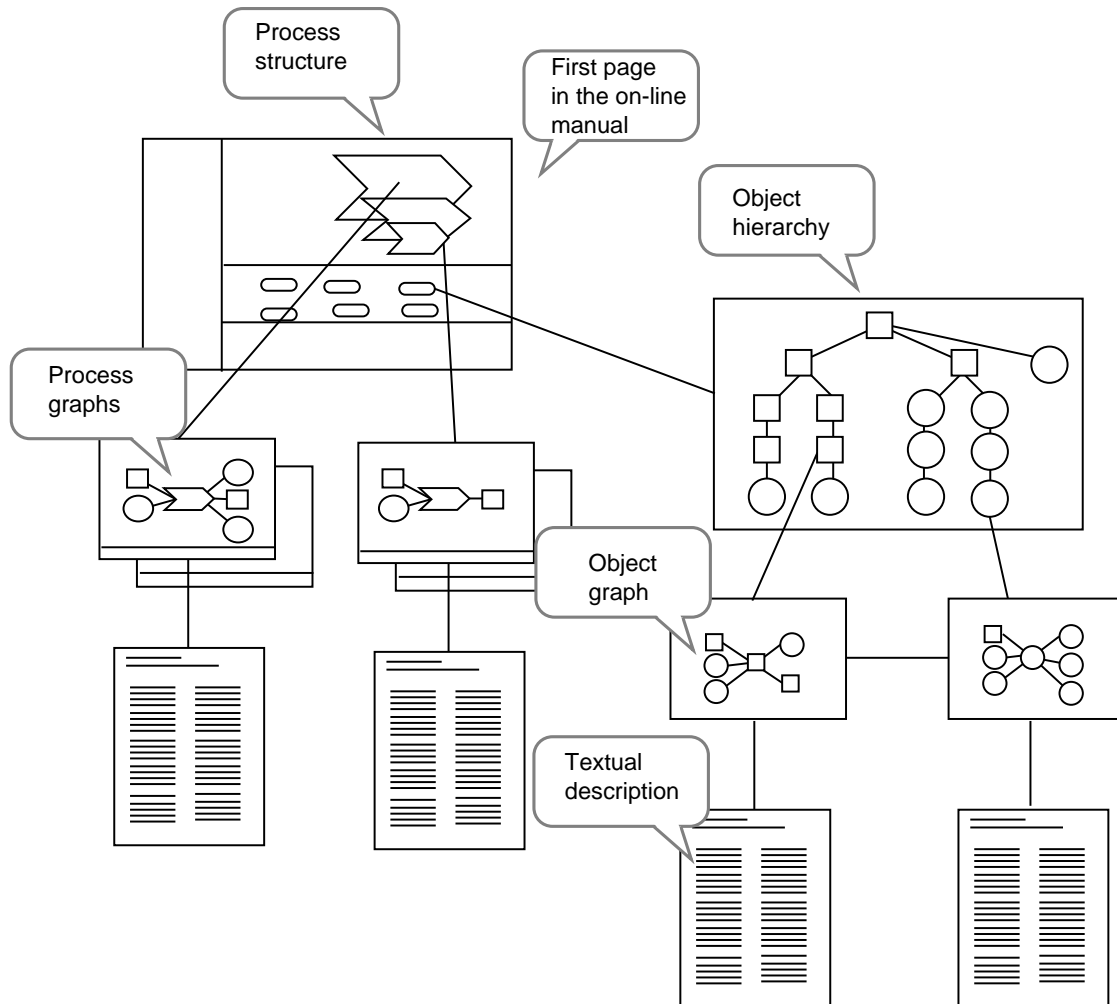

Figure 1. A schematic picture of the structure of the on-line manual. The two overviews pictures are the process structure and the object hierarchy. From those, each process and object description can be reached.

3 Method

3.1 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.

3.2 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.

Cognitive abilities

Subjects were first tested on their cognitive abilities using a subset of the Düremann-Sälde battery [Psykologiförlaget 1971], which is a Swedish standardised test of cognitive abilities. The cognitive tests took approximately 2 hours per subject and the tested abilities, as described in the test manual, were:

- *verbal* ability, tested in a synonym test where the subject were supposed to pick one out of five words meaning the same as a given word.
- *logical-inductive* ability, tested through making the subject pick one image out of five based on it being different from the four other.
- *perceptual analysis* ability, tested through requiring the subject to draw imitations of images.
- *spatial* ability, tested in three different tests:
  - rotation of images where the subject should choose, by turning the images in their mind, the images that were identical with the image in the task (the number of correct images differed in each task, but they always came from a group of seven).
  - identification of left or right hand in pictures of hands that were turned in different ways.
  - a blocks test (Koh's block test) where the subject makes a pattern with blocks to be identical with a pattern displayed on a card.

The results from the cognitive tests were transformed into stanine-scores (1 to 9) based on the standardisation of the tests on a sample of 166 persons balanced for age (between 15 and 64) and gender.

The purpose of testing other cognitive abilities apart from spatial ability, was in order to exclude the possibility that it was general intelligence or some other ability which was more closely related to the subjects navigational skills.

Self-estimated knowledge of the SDP method and of spatial ability

In a questionnaire subjects were asked to estimate their own knowledge in the subject area, on a scale from 0 to 5. The questions concerned both the domain of the on-line manual (the SDP method), the actual on-line manual and their experience with it, and also their computer literacy in general, as well as their knowledge of other hypermedia tools, and point-and-click interfaces. Finally, they were asked about their map-reading skills and their sense of location in the real world. Our hypothesis was that their map-reading skills would be related to their navigational skills.

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 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 (see Bladh and Höök 1995) 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.

- Some of the answers to the queries were in the object-view and some in the process-view, that to see if there were any differences in the way of seeking information in the different views.

The queries were:

1 Vad heter relationen mellan objektet ROT och objektet IOT? (What is the relation between the object ROT and the object IOT?)

2 I vilken ordning ska delaktiviteterna i processen NodeS påbörjas? (In which order should the sub-activities in the process NodeS be applied?)

3 Beskriv alla relationer mellan objekten SWI, OTS och IS och specificera sambandet mellan OTS och IS. (Describe all the relations between the objects SWI, OTS and IS and specify the relationship between OTS and IS.)

4 I vilken process skapas först objektet OTS? (In which process was the object OTS first produced?)

5 Vilka är de formella krav (exit criteria) som ska vara uppfyllda för att man ska få lämna IOM-processen? (Which are the formal criterion (exit criteria) which must be fulfilled in order to be allowed to exit the IOM process?)

6 I vilken ordning ska delaktiviteterna i processen LNRM påbörjas? (In which order should the sub activities in the process LNRM be applied?)

The order of the questions were the same for all subjects. The reason being that it was easy to stumble over information which would be relevant in questions posed later on.

The on-line manual was available on Sun workstations and implemented in Framemaker™.

The performance on the solving the six tasks was recorded on video and analysed. Task completion time was calculated from the first "click" to the last written letters in the answer. Number of "clicks" in the graphs was counted for each task, and a map depicting how a particular user has moved in the on-line manual between graphs and texts was drawn.

4 Results

The results of the study show that our hypothesis of a correlation between spatial ability and navigation in the hypermedia tool was indeed correct, but that we should make a distinction between different aspects of spatial ability. We start by describing our analysis of the cognitive tests and the different aspects of spatial ability.

4.1 Patterns of cognitive abilities

A factor analysis[1] of the results of the six cognitive tests revealed three underlying factors, with two tests with high loading in each factor (see figure 2). 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.

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

Figure 2. A factor analysis of the cognitive tests.

What is especially noteworthy here is that the pattern obtained seem to put in question the test manual's classification of these tests. The third factor seem to relate to spatial ability, but the blocks test does not belong here. It instead goes together with another test requiring manual manipulation of the test materials. This could indicate that from a psychological point of view 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.

4.2 Cognitive ability and task completion time

We checked for any correlation between the individual tests, the three underlying factors, the users previous experience and knowledge, etc. and their completion time/number of clicks to solve the navigational tasks. We could only find one correlation, namely between completion time of the navigational tasks and the subjects spatial ability as measured with the two tests in factor 3 ($r = .56$, $p < .005$). No other

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[1] The factor analysis was done based on the results in each cognitive test, not on the stanine points. In order to compare the points obtained for each test, they are first converted into so-called z-points, i.e. comparable points for the different tests.

correlations achieved significance. The correlation between the completion time and the blocks test was for instance only $r = .04$.
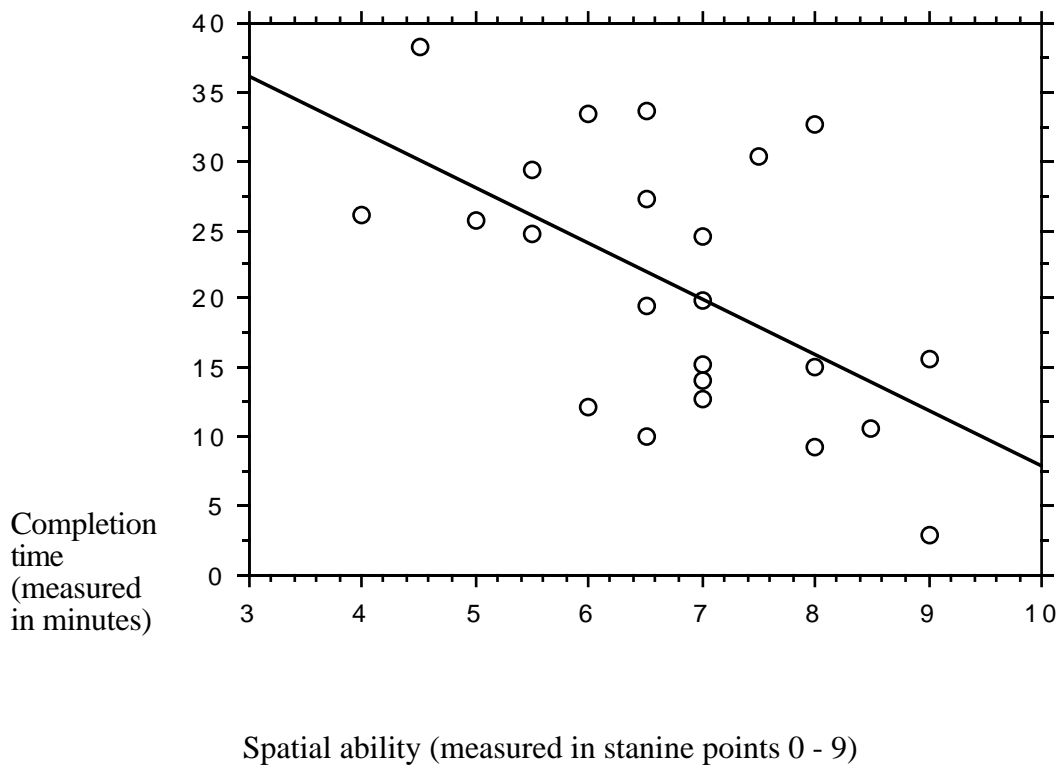

Spatial ability (measured in stanine points 0 - 9)

Figure 2. The correlation between completion time and spatial ability.

In figure 2, we see how the subjects are spread with respect to task completion time and the spatial test. The spatial tests are converted into stanine scores (between 0 and 9), and we see that this particular group of subjects are spread from 4 to 9 on that scale. The facts that the subjects lie slightly higher on this scale than the normal population which was measured in the Düreman-Sälde test battery, was expected since this group of subjects are fairly well-educated and work with tools and problems which require these kinds of abilities.

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 figure three, 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

Figure 3. 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.

Task 2 and 6 were designed to be the same tasks but for different processes in the domain. Our hope was that subjects with a high ability, would perform much better for the second task. That would in such a case, indicate that they had built a mental map which allowed them to navigate faster to the answer. In figure 4 we see the results for the whole group of users where we see that the time and number of clicks are slightly less the second time around. There was no significant difference between the subjects with low and those with high spatial ability, only a slight difference in time and number of clicks. Perhaps the difference between users with low and high spatial ability does not necessary have anything to do with learning the structure faster, but perhaps more to do with faster getting a grip of the structure as communicated by the interface. This should be tested further with tools where both groups are complete novices with respect to the content and organisation of the information.

Task	Time	Click
2	1.76	4
6	1.37	3

Figure 4. Median time spent and median number of clicks spent for solving the tasks number 2 and 6.

Somewhat surprising is that the subjects self-estimated knowledge of the method, SDP, is not correlated with completion time. Instead, their previous experience of the on-line manual and completion time for the navigational tasks are related ($r=.428$, $P<.05$), and experience of actually applying SDP (which normally also involves using the on-line manual) is also related to completion time ($r=.417$, $P<.05$).

We draw two conclusions from our material. First, that there seem to be a correlation between users' spatial abilities (as measured by factor 3) and their ability to use the hypertext based system.

Second, the correlation's obtained between these factors, together with the non-correlation between the ability to use the hypertext system and the blocks test or other visio-spatial tests, gives some support to the hypothesis that spatial navigation in the mind and spatial navigation in the world are, somewhat surprisingly, rather independent cognitive abilities. Or at least, that there seem to be differences between them that warrants further studies to clarify the issues involved.

4.3 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 (1985) 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 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.

4.4 Confidence and efficiency

After completing each of the six tasks, the users were asked to evaluate how efficient they thought that they had been in completing the task. Here we could see a clear correlation between how quickly they completed the tasks and how well they thought they had performed.

Task	Time	Click
1	r = .679	r = .525
2	r = .576	r = .600
3	r = .405*	r = .433
4	r = .550	r = .545
5	r = .464	r = .434
6	r = .669	r = .695

Figure 5. Significant correlations for all six tasks between time/click and the subjects own estimation of how well they solved the task ($p < 0.05$). (* expect for task 3 where $p = 0.055$).

In figure 6 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 and looked at each graph several times in order to make sure that they had understood the relations correctly. An example of a graph that they had to study can be found in figure 7. As we see, each graph in itself is fairly simple.
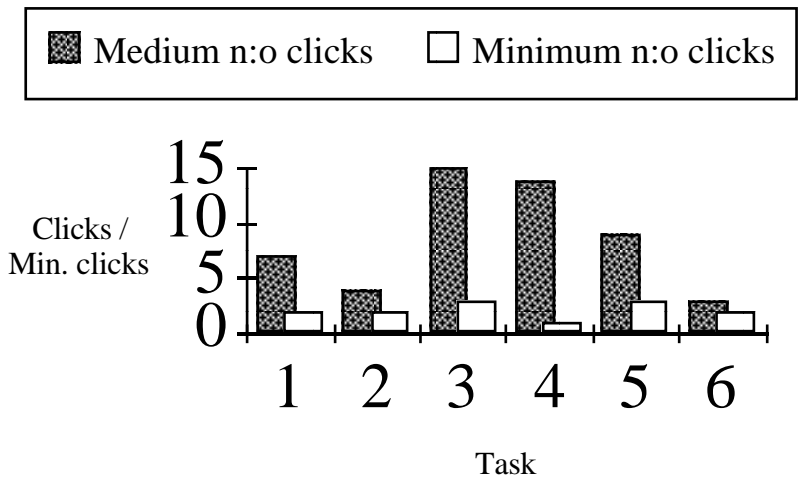
Figure 6. Medium number of clicks performed by the subjects compared with minimum number of clicks possible for each of the six navigational tasks.

Task 4 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 were the answer was. So, in fact, the users did not perform too badly in terms of visiting too many nodes in the information space.
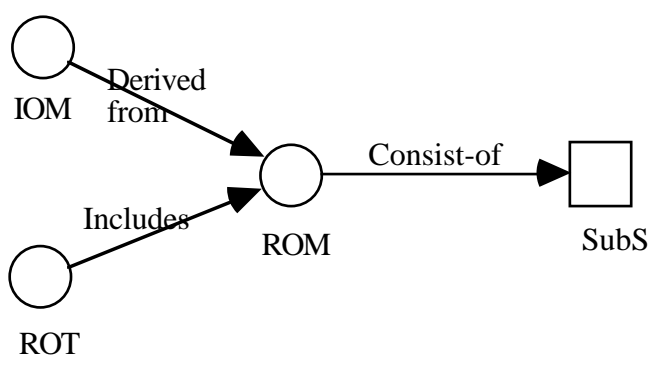

Figure 7. An example graph from the on-line manual. The graph shows how the different objects are connected and the names of their relations.

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 figure 8, 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 in order to find the answer.

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

Figure 8. How confident the subjects were in having found the correct answer[2] to the six tasks divided into two groups: low and high confidence.

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.

5 Discussion

Our hypothesis that navigation in the on-line manual could be correlated with spatial ability turned out to be correct. There we no correlations 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.

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.

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[2] Some subjects did not complete all tasks which is why not all columns add up to 23.

6 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. 1995) which is also supported by the results of Stenning and Oberlander (1995). 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. This would furthermore have avoided the pictorial characteristics of the interface altogether, and might therefore be better suited for some users.

Second, hypermedia is sometimes provided together with a navigation map 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. Let us take a hierarchical file system with folders and files in folders as an example. 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 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.

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[3]) 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

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[3] Netscape is a so-called web-browser by which World Wide Web pages can be retrieved and shown.

1988). It is not clear exactly what is improved by providing the kind of aids as outlined above.

Some of these ideas are explored in a system we are designing (Höök et al. 1996, Espinoza and Höök 1996) which we aim to study further.

Acknowledgements

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