# Search Strategies in Hypermedia Navigation and Spatial Abilities: A Comparison with Physical Navigation

Aurélie Brouwers

Research Fellow F.R.S-F.N.R.S, Université catholique de Louvain, Belgium
aurelie.brouwers@uclouvain.be

**Abstract.** This article focuses on spatial abilities mobilized during hypertext navigation. Based on the evidence that spatial cognition plays a central role in navigation, we present an experiment involving information search tasks both in physical environment and in hypermedia environment. We investigate how users make use of their spatial abilities to search information in hypermedia, by comparing their performances in hypermedia navigation and physical navigation. As data collection and analysis are still in progress, we present preliminary results based on available data.

**Keywords:** hypermedia, navigation, visuospatial abilities, spatial cognition.

## 1 Introduction

The term "navigation" has been used for decades to describe the interaction between a user and a hypertext system [1]. The use of this spatial metaphor is backed by at least two kinds of research results. On the one hand, a number of studies [2]–[4] have uncovered correlations between subject performance in hypertext navigation and performance in standardized tests of visuospatial cognitive abilities. On the other hand, hypertext users have been shown to use spatial metaphors extensively and systematically when they speak of their interaction with hypertext [5], [6], indicating that these metaphors play a role in the way users think about this interaction.

This article focuses on the role of spatial cognition and specifically visuospatial abilities in information search in a hypertext environment. We investigate how users make use of their spatial abilities to search information in hypermedia, by comparing their performances in hypermedia navigation and physical navigation. First, we will review relevant research in spatial cognition and information search. Next, we will present an experiment requiring subjects to interact with a physical environment and a hypertext environment. As data collection and analysis are still in progress, we will present preliminary results based on available date.

## 2 Spatial Cognition and Cognitive Mapping

The concept of cognitive map is central to the field of spatial cognition research. Siegel and White distinguished between landmarks, routes and survey representations as

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components of cognitive maps. Landmarks are features of the environment that are saillant to the subject. Routes connect different landmarks. Survey knowledge organizes routes into configurations that provide the subject with an overview of their environment. Siegel and White described a “Main Sequence” for the development of spatial knowledge that goes “from landmarks, to route-maps, to survey-maps” as “a process of going from association to structure, and of deriving simultaneity from successively” [7]. As Siegel and White [7] pointed, cognitive maps are not very much “map-like”: they tend to be fragmented and are prone to distortion. Hence, we prefer to speak about spatial mental representations.

Moeser [8] compared the navigation of student nurses who has been working in hospital for three years and the navigation of naive subjects who studied the hospital map. He showed that the naive subjects performed significantly better on objective measures of cognitive mapping (distance estimation, drawing plan, etc.) than did the nurses. He concluded that the extended and intensive experience of an environment doesn’t systematically provide the individual with survey knowledge of it. Each person tends to construct mental representations that include relevant elements for their own use of the environment. For these student nurses, landmarks and route knowledge seemed sufficient to navigate their professional environment.

In hypermedia research, the concept of cognitive map has been used to describe the user’s mental representation of the hyperdocument’s organization [9]–[12]. Following Siegel and White’s model, several studies in hypermedia research (e.g. Sedig et al.[13]; Kim & Hirtle [11]; Edwards & Hardman [14]) relied on the view that landmarks, routes and survey knowledge are acquired successively. This implies that survey knowledge is necessarily the most advanced form of spatial knowledge. Kim & Hirtle [11] and Edwards and Hardman [14] emphasized that subjects with survey knowledge are rarely disoriented in hypermedia.

Spatial mental representations of the environment can be constructed either through primary learning (i.e. by observing the actual environment directly) or through secondary learning (i.e. by means of an external presentation, such as a map) [15]. Secondary learning may represent an alternative way of acquiring spatial knowledge (compared to Siegel and White’s “Main Sequence”), as survey knowledge may be acquired directly from a map, without being derived from route knowledge acquired through navigation. While this distinction is relevant to physical environments, its application to hypermedia environments is problematic, as the organization of hyperdocuments only exists in representations, be they external (e.g. concept maps, or the system’s interface itself) or internal (the mental representation constructed by the user). Hence, the very notion of primary learning seems void in the context of hypermedia. However, the notion of learning routes from navigating (which can in turn be elaborated into survey knowledge) as opposed to learning survey configurations from a site map (which in turn can be converted into specific routes from one page to another), stays relevant in this context.

People differ in their spatial abilities. Research by Goldin and Thordyke [16] showed that the difference between “poor cognitive mappers” (subjects with lower spatial abilities) and “good cognitive mappers” (subjects with higher spatial abilities) may lie in their ability to construct spatial mental representations of their environment, both from navigation and from maps. However, when forced to study a map so as to construct a reliable representation of a given environment, “poor cognitive mappers” navigated as efficiently as “good cognitive mappers” suggesting that “when utilizing equally accurate knowledge, poor cognitive mappers can navigate as well as good cognitive mappers”[16].

Spatial visualization abilities of hypermedia users had been shown to predict their navigation performance by previous studies [2]–[4]. Spatial visualization can be defined as an internal spatial ability. Such internal abilities, requiring “a purely mental effort to obtain the correct answer”, were distinguished by Dahlbäck et al. [4] from external spatial abilities that involve the active manipulation of physical objects (such as the arrangement of block in a pattern defined by a picture of arranged blocks), which did not correlate with performance in hypertext information search.

Carroll [17] showed that the spatial visualization factor assessed by these tests involves the cognitive processing required to mentally encode and manipulate spatial shapes. He also noted that the successful completion of tests such as VZ-1 and VZ-2 [18] requires a mental representation in three dimensions. This would explain his observation that individuals who perform well in task in 2-D environments tend to be also performing well in tasks in 3-D environments.

Interestingly, the tests used to assess spatial visualization abilities actually require subjects to process external representations (pictures) into mental representations they need to manipulate internally in order to complete the task. Constructing a reliable mental model from an external representation (as opposed to using a mental model to act in the real world, or to using an external representation to act in the real world).

Research on the use of concept maps to represent hypermedia structure has yielded ambiguous results. Dee-Lucas & Larkin [19] showed that a structured overview of hypertext had beneficial effects on the memorization on the document’s textual contents. Vörös et al. [20] showed that concept maps helped subjects with poor spatial abilities to better remember the hypermedia structure after their navigation. However, their study did not test whether subjects with more accurate cognitive maps of the hypertext navigated more efficiently (i.e. performed better on search tasks). In Nilsson & Mayer’s [21] studies, subjects who used a hyperdocument with a non-clickable map performed better than subjects who used the same hyperdocument without the map at first, but the comparison inverted over time, showing the map could become cumbersome during navigation. Scott & Schwartz [22] showed that while processing a hypertext concept map generated additional cognitive load, the extra effort paid off when the spatial relationships depicted by the map matched the semantic relationship of the hypertext’s contents.

## 3 Research Question and Hypothesis

Our research question is the following how do spatial visualization abilities come to play in hypermedia navigation?

Spatial visualization abilities could play a role (1) in the construction of a mental model of the hypertext's organization, (2) in the use of this mental model to make navigational choices, or (3) in the use of the hypertext interface and navigation tools (as an external representation of its organization) to make navigational choices.

Based on our literature review, we hypothesize that spatial visualization abilities mainly play a role during the construction of the hypertext mental model. To test this hypothesis, we set up an experiment requiring subjects to perform a series of information search tasks in a physical and a hypertext environment. Our experimental protocol allows us to proceed with intra-subject comparisons of navigation behaviors in hypertext and in real life, as well as inter-subjects comparisons based on their level of spatial visualization abilities (cf. infra). It also allows us to clarify the role of map usage during hypertext navigation.

# 4 Method

## 4.1 Fields of Observation

Our experimental protocol includes tasks to be completed in a large-scale physical environment and a hypermedia environment. The Planckendael (Belgium) zoo was chosen as the physical environment, as it met all of our requirements. In addition to making different animals available for public display, the zoo includes and organizes information (about animals) spatially (e.g. in the form of posters presented at each animal's enclosure). It clearly bounded space corresponds to a bounded informational space. In this context, information search tasks can be designed, involving the processing of both spatial and semantic information by subjects. Also, it is an outdoor environment, which allows GPS tracking of our subjects.

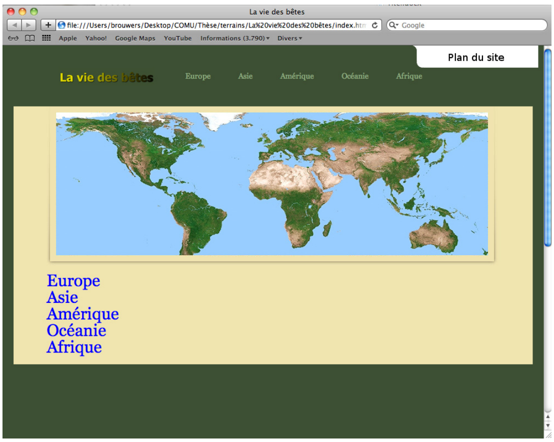


**Fig. 1.** Home page

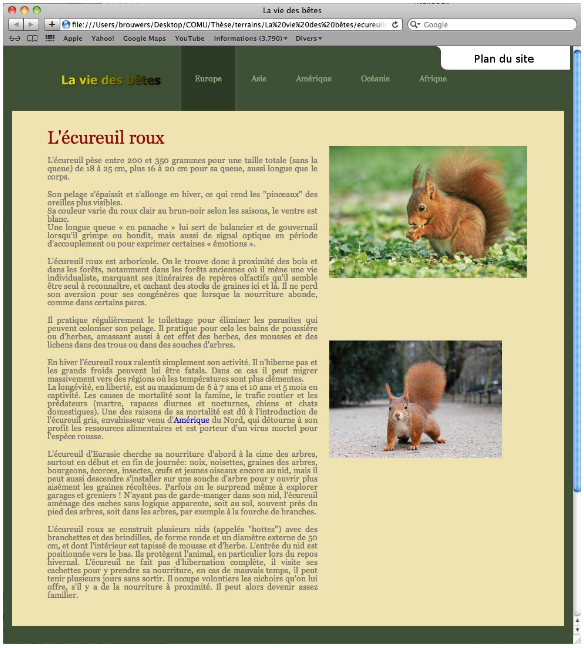


**Fig. 2.** Animal page

We designed a forty-five-page hypermedia environment on wildlife, including information on different animal species that are not visible at the zoo. Each animal is presented on a separate page. Pages presenting an animal species are grouped according to the continent on which the species lives. This hierarchical structure mimics that of the zoo, which dedicates a part of its space to each continent.

## 4.2 Participants

Students enrolled at the Université Catholique de Louvain (Belgium) are currently being recruited as voluntary participants in our experiment. Ten subjects have completed the experiment so far. Twenty more subjects will be tested in the near future.

## 4.3 Individual Variables

Subjects are tested with respect to two types of cognitive abilities. On the one hand, we use VZ-1 and VZ-2 tests from the kit of factor-referenced cognitive tests [18] to assess our subjects spatial visualization abilities.

On the other hand, we test our subjects with a discourse comprehension test [23]. As information search in hypermedia involves the processing of both semantic and spatial information [24], we use this test to control our subjects verbal abilities.

### 4.4 Tasks

Subjects are required to perform five information search tasks in the physical environment, and seven information search tasks in the hypertext environment. For each task subjects are instructed to answer a specific question about an animal species, the answer of which is located at the animal's enclosure in the zoo, or on the animal's page in the hypertext. The questions used in the two environments are different.

### 4.5 Procedure

Prior to the navigation, half of the subjects (randomly selected) are asked to study the map of the environment they are about to interact with (subjects either study both maps, or none). Subjects are tested on their memorized map, and the study is repeated until they learned the map perfectly. According to our hypothesis, subjects with low visual-spatial abilities who studied the map should perform similarly to with high visual-spatial abilities, as visuospatial abilities are supposed to play a decisive role in the construction of the mental model of the environment.

During the navigation, subjects are provided with the task questions one at a time. When the subject thinks to have found the answer, he notifies the experimenter. If the answer is correct, he is given the second task question. If not, the subject has to continue searching. While searching subjects are asked to verbalize their navigation intentions before executing them. In physical environment, subjects are asked to estimate the direction of the searched information. During navigation, subjects have the opportunity to consult a map. The hypertext map can be accessed though a tab (preventing concurrent navigation and map viewing) and in the zoo, subjects are required to stop whenever they want to view the map. The aim is to force subjects to verbalize their use of the map.

In each condition (map-study vs. no-map-study), half the subjects navigate the zoo prior to the hypertext, and the other half navigate the hypertext prior to the zoo, in order to control the training effect of one navigation on the other.

Finally, subjects are submitted to the spatial and verbal ability tests after the two navigation sessions, in order to avoid a sense of demotivation due to poor performance in these tests.

### 4.6 Data Collection

In the zoo, navigation is recorded using a Looxcie, a mini camera equipped with a microphone. A GPS tracker, Map My run, an android application, records the routes. Hypermedia navigation tasks are recorded using TechSmith Morae, a software suite that captures screen and webcam activity, as well as mouse and keyboard input (e.g. clicks, menu selection, etc.).

# 5 Preliminary Results

At the time of writing, we have tested ten subjects and have started to analyze the collected data for nine of them. Our current analysis focuses on the influence of the study of the map on navigation behavior and efficiency. Table 1 presents some of the data that were collected for these subjects.

**Table 1.** First data

| | | | Zoo | | | Hypertext | |
|---|---|---|---|---|---|---|---|
| Subject | Condition | VZ-1+ VZ-2 score | Total search time | Total distance | Map views | Total search time | Map views |
| 1 | no-map-study | 1 | 01:08:00 | 5,57 km | 7 | 00:28:38 | 0 |
| 2 | no-map-study | 6 | 00:57:35 | 3,59 km | 12 | 00:11:40 | 10 |
| 3 | no-map-study | 12 | 00:45:00 | 6,49 km | 8 | 00:27:57 | 0 |
| 4 | no-map-study | 16 | 00:59:21 | 4,60 km | 6 | 00:09:58 | 0 |
| 5 | no-map-study | 17 | 01:12:00 | 4,13 km | 19 | 00:30:00 | 0 |
| 6 | map-study | 2 | 01:10:00 | 5,50 km | 12 | 00:12:18 | 0 |
| 7 | map-study | 12 | 00:38:42 | 2,54 km | 4 | 00:11:30 | 7 |
| 8 | map-study | 19 | 01:04:00 | 6,68 km | 8 | 00:09:09 | 0 |
| 9 | map-study | 22 | 00:21:08 | 3,54 km | 7 | 00:18:57 | 0 |

Contrary to previous research results, scores to the spatial visualization tests did not correlate significantly with time spent navigating in either of the environments, or with distance traveled in the zoo (using Pearson's correlation coefficient), although this may be due to the low number of subjects (N=9) in our current dataset.

Our current observations for the physical environment are not consistent with previous studies [16]. Indeed, subjects who studied the map of the zoo are not necessarily more efficient than others ($Mean_{map\text{-}study}$ = 48:28; $Mean_{no\text{-}map\text{-}study}$ = 1:00:23). However, subjects who studied the site map prior to navigation completed their tasks more quickly than the other subjects ($Mean_{map\text{-}study}$ = 12:58; $Mean_{no\text{-}map\text{-}study}$ = 21:39).

We observed that the subject with the lowest results in VZ-1 and VZ-2 test in the map-study condition was able to use her survey knowledge in the zoo, as she was able to accurately estimate the direction of the searched item. However, she was unable to convert her survey knowledge into a proper route plan, as the geodesic distance between her current location and her planned destination did not correspond to an actual path in the zoo. In this case, a survey vision of the environment proved to be of little help to our subject. In the hypertext environment, she successively browsed the main nodes of the interface (the continent pages) to gain visual access to the different links (routes) to specific animal pages, until she identified a potential target node. In this case, she used her memory of the overall (survey) organizing principle of the hypertext to structure her use of the interface (as an external representation of the system's structure).

Finally, the majority of our subjects did not use the sitemap tab while navigating. When asked why they didn't, most subjects replied that they feared the concept map would confuse them, as they felt sitemaps are generally useless.

## 6 Conclusions and Future Work

The experiment presented in this paper aims at better understanding the role of visuospatial abilities in hypertext navigation. To do this, we compare the information search strategies developed by subjects in a physical environment and in a hypertext.

Observation and analysis are still in progress. Nevertheless, preliminary results indicate that the study of the map before hypertext navigation does make navigation easier for individuals with low visual-spatial abilities. This suggests that the visuospatial abilities may play a more decisive role in the construction of the mental representation of the environment than in the use of this representation during navigation.

Future qualitative analyses of our data will attempt to identify and compare strategies for navigating our two environments. Specifically, we intend to identify (1) the type of information subjects use to make navigation choices (route vs. survey knowledge; their mental model vs. the map vs. cues in the environment) and (2) the cognitive processes they perform during navigation to use this information, e.g. coordinating the map with the territory, or converting survey knowledge into a route plan. As far as the effect of spatial abilities is concerned, we intend to observe whether subjects with low spatial abilities develop only route knowledge, whether studying the map prior to navigation allows subjects with low spatial abilities to develop survey knowledge, and whether they are able to use it to navigate the environment.

As part of our analyses, we will diversify the indicators we use to assess navigation efficiency. We will use the efficiency metric proposed by Smith (1996) for hypertext navigation, which combines three kinds of indicators: a measure of the redundancy (repeated visits to the same nodes) of navigation, a ratio between the number of nodes required to complete a task and the number of different nodes visited, and an indicator of the successful completion of the task. We are working on an adaptation of this metric to the physical environment, using the traveled distance instead of the number of visited hypertext nodes.

We are hopeful that our work will yield recommendations for hypertext designers on how to provide users with low spatial abilities with survey information they can easily convert into route plans.

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