WEBSITE NAVIGATION: THE EFFECTS OF SPATIAL CUES
ON SEARCHING BEHAVIOR

A Thesis
by
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ABSTRACT

WEBSITE NAVIGATION: THE EFFECTS OF SPATIAL CUES ON SEARCHING BEHAVIOR

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The aim of this study was to improve website navigation by reducing disorientation and cognitive overload. From the basis of recent findings in grounded cognition and embodied cognition, we developed two website navigation modalities designed to enhance ego-centered mental simulations of movement. Two forms of spatial cues were used for this purpose: spatial consistency and animations of movement. The performance of two groups of undergraduate college students on a searching task using these two website modalities were compared with the performance obtained by a third group using a traditional hyperlink modality. We found that the addition of spatial cues improved navigation in its efficiency and accuracy, and allowed participants to use more network navigation (vs. hierarchical navigation). We conclude that mental simulations of physical interaction can be stimulated by a navigation modality, which benefits navigation. However, we also found that when participants explored the website in a
consecutive second session using the same navigation modality, the improvement of performance of participants was better in the hyperlink modality. We conclude that the addition of spatial cues, while easing navigation, can also hinder learning.
CHAPTER I

INTRODUCTION

Background

Searching for information on the world wide web implies different activities. For example, the process of finding a recipe for the next family dinner involves typing keywords, selecting relevant hyperlinks in lists ordered by relevance, date, or other characteristics, as well as navigating through the visuo-spatial interface of the web browser from recipe to recipe. Two different dimensions are found at stake in these activities and all hypermedia navigation: the semantic dimension of the information system, and the spatial dimension induced by the graphical browser (Conklin, 1987). As Dourish and Chalmers (1994) underlines, the spatial dimension found in information navigation, and that legitimizes the term of navigation itself, only envelops the semantic structure of information. The spatial dimension is only an emulation of space, added to provide a more natural interaction with the information system (Dourish & Chalmers, 1994), and supported by the user's natural visuo-spatial abilities (Conklin, 1987).

Additionally, Schnotz and Heiss (2009) consider that spatial orientation in learning with hypermedia is only a step on the way to constructing knowledge of the information structure itself. Thus, the spatial dimension of hypermedia is auxiliary, but nevertheless of key importance in navigation. For this reason, in the present study we will manipulate the spatial dimension of hypermedia.
User Control

Thanks to the spatial dimension provided by the graphical browser and the power of computer processing of hyperlinks, the activity of navigation is made possible. Navigation exists because in hypermedia, and contrary to traditional media, users are in control of their own access to information (Scheiter & Gerjets, 2007; Boechler, 2001). A book, article, or video-based material, would typically have a linear structure. Hypermedia, however, can have a variety of non-linear structures. Although non-linear elements such as references and footnotes have existed before hypermedia, the computer processing of links in hypermedia brings user control to a much higher level (Conklin, 1987). The freedom provided to the user in hypermedia is at the root of the interest of educational researchers for hypermedia, because of the deeper comprehension of information that results from hypermedia navigation (Schnotz & Heiss, 2009).

However, the freedom of the user can cause cognitive overload (or overhead) and disorientation (Conklin, 1987; Scheiter & Gerjets, 2007; Amadieu et al., 2009). Amadieu and colleagues (2009) define disorientation as a psychological state resulting from difficulties in constructing the pathways across elements of an information system and in constructing a mental representation of the physical and conceptual space of the structure. Cognitive overload is an excessive load on working memory, due in hypermedia to the contemplation of different choices of navigation in the network and their consequences on information localization (Conklin, 1987). Research on hypermedia has explored various methods to lower cognitive overload and disorientation, and overall improve the efficiency of navigation.
The Use of Semantic Scaffolds

Schnotz and Heiss (2009) enhanced hypermedia by providing semantic scaffolds to users in a learning setting. The authors improved learning for participants with higher learning abilities, but hindered learning for participants with lower learning abilities because these participants suffered from an overloaded working memory. This led the authors to warn about the use of semantic scaffolds and the possible hindering effect semantic scaffolds can have on learning in hypermedia. In sum, adding another dimension such as semantic scaffolds to a task in hypermedia is likely to have negative effects because two sources of mental effort are already present: task and navigation. Rather than adding new semantic material, we suggest that the spatial dimension of hypermedia should be improved.

The Use of Metaphors

A commonly used method intended to reduce cognitive overload and disorientation in hypermedia is the use of metaphors. In human-computer interaction, metaphors such as the desktop metaphor are commonly encountered. In the case of information systems, metaphors have been used for example in the form of a city (Dieberger & Frank, 1998), a house, (Dørum & Garland, 2011), a filing cabinet and piles of documents (DiGioia & Dourish, 2005), or books and folders (Hsu & Schwen, 2003). Metaphors have the power to explain the functions of an electronic system like an information system by mimicking a system from the physical world. This provides the user with a set of rules describing what is possible and what is impossible with the electronic system. The drawback is that metaphors also import the constraints of the real world to the electronic system (Benyon and Hook, 1997). For example, only a limited
number of documents can be placed visibly on a desktop because both the documents and the desktop have unalterable physical dimensions. This limit has been imported in most traditional computer desktop systems.

However, metaphors also always provide vocabulary to describe the capabilities of a new system. The need for descriptive vocabulary emerges in the process of collaborative design of a new system, and metaphors successfully fulfill that need (Boechler, 2001). We believe that providing vocabulary is the first reason why metaphors first emerge. Also, as Dillon and colleagues (1990) underline, emulating a referent in its worthless details is different from extracting the useful properties of the referent. Thus, because metaphors always import concepts from the physical world into the electronic world, they always import a core property of the physical world, which is space. In the example of the desktop metaphor, the heart of the metaphor can be summed up as the spatial organization of elements on a plane, with the property of object permanence: a document placed in a certain corner of the desktop will remain in this place. This allows users to organize their documents in the electronic world like they organize them in the physical world, by assigning a location to certain objects regardless of semantic criteria (Dourish & Chalmers, 1994). In sum, we suggest that metaphors provide only two advantages. Firstly, metaphors provide vocabulary to actors of the design process. Secondly, metaphors import an elaborate spatial dimension from the physical world into the electronic world. For this reason we argue that implementing spatial properties into information systems would provide the advantages of metaphors without importing their limitations.
The Use of Spatial Support

Another technique used to reduce disorientation and cognitive load is to make the information structure more visual and more spatial with the help of spatial support such as maps or organizers (Boechler, 2001; McDonald & Stevenson, 1998; Nilsson & Mayer, 2002; Stanton, Taylor, & Tweedie, 1992). However, results show that maps sometimes hinder learning of the information structure (Stanton et al., 1992). Nilsson and Mayer (2002) found that maps providing a lot of information can ease navigation but also hinder learning of the information system. The authors recommend organizers providing structural cues but withhold the path to the search goal. Also, it has been noted that navigational aids can in certain cases hinder navigation performance (Stanton et al., 1992), one reason being that they place the user in a split-attention effect between the contents and the aid (Chandler & Sweller, 1992). Additionally, from a practical point of view, maps and other types of navigation support add to the number of elements already on the screen, degrading the design, cluttering the page, and increasing the workload of the designer. For these reasons, spatial support can only be regarded as an ad-hoc correction of the symptoms of a failing navigation.

One reason of the failure of navigational aids is that they are built under the assumption that spatial navigation is based on the use of a cognitive map (Dillon, Richardson, & McKnight, 1990; Toleman, 1948). More recent research has tackled this assumption. Burgess (2006) argued that allocentric internal representations, such as cognitive maps, coexist with egocentric internal representations. The author describes that the two systems can be used simultaneously but one system is mainly used at a time.
The motion of the self, the size and structure of the environment, and the experience of the environment are factors that influence the type of representation internally used.

Franklin and Tversky (1990) also have shown that localization of objects in space depends on the position of objects in relation to the body axes because of the potential of interaction between the body and the object. These results suggest that cognitive maps could be only one way of representing the environment, with ego-centered representation as a possibly more spontaneous alternative according to the properties of the environment.

**Grounded Cognition**

Internal representations, or simulations, are a core concept in the field of grounded cognition (Barsalou, 2008). According to the perceptual symbols system theory (PSS; Barsalou, 1999), brain activations in the sensory-motor area are stored as perceptual symbols. The sensory-motor perceptions are divided into multiple components before being stored as perceptual symbols. The physical modality of perceptual symbols is the neural activation pattern. Recall and retrieval of memories consist of the reactivation of neurons in the same pattern. For this reason, when a memory is recalled, it constitutes a simulation of the original event, not holistically, but in its relevant dimension. This point of view is supported by neuroimaging data showing that the retrieval of perceptual knowledge is supported by the relevant perceptual brain regions (Goldberg, Perfetti, & Schneider, 2006). In the embodied cognition literature, bodily states and bodily movements are found to have effects on decision-making (Reimann et al., 2012), emotions (Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009), and
perceptions (Niedenthal et al., 2005). It is accepted that these bodily states and movements can be substituted by mental simulations leading to similar effects (Reimann et al., 2012; Labroo & Nielsen, 2010; Niedenthal et al., 2009).

The particular case of simulations in spatial processing is well documented in the literature. In 1971, Shepard and Metzler introduced the concept of mental rotation by showing that the duration of comparison of objects seen from different angles was a linear function of the difference in angle of rotation. They concluded that a mental rotation of the object of comparison took place to inform the decision of similarity. Additionally, Jeannerod and Frak (1999) have shown that judging the ease of a described motor task took longer when the movement was less feasible. This suggests that the process consisted of a cognitive simulation of movement rather than of an abstract or algorithmic operation. Thus, mental simulations are not limited to mental rotations.

Even metaphorical fictive movement described in text, such as the verb "to run" in the sentence "the road runs through the desert" was found to be mentally simulated (Matlock, 2004). The type of terrain, length of movement, and speed suggested by the motion verb all affected the duration of mental processing, lengthening the duration of the process in the case of longer routes, slower motion, or rougher terrain.

As spatial representations can use different modalities (allocentric vs. egocentric), simulations can be of different types. Kosslyn and colleagues (1998) found that brain activations differed when participants mentally rotated images of hands versus abstract cubic structures. The primary motor cortex was involved only when a hand was mentally rotated. Richter and colleagues (2000) suggest that the perspective taken by the
participant of the experiment, internal versus external, explains this results. This supports the idea that a visual cue such as a body part in a spatial task induces a different mental processing of the task, involving the mental simulation of bodily movement, from an internal perspective. Recent findings from Elder and Krishna (2012) support this idea. They found that on a pictorial advertisement, the orientation of the handle of a coffee mug (and other similarly graspable products) towards the left or towards the right influenced the power of the stimulus on intentions of purchase. When the orientation of the product matched the participant's dominant hand, the effect of desirability of the product on intention of purchase was enhanced. The correspondence of participant's dominant hand to orientation of the product also implied an increase in mental simulations.

Recent research indicates that covert mental motor simulations arise spontaneously from the perception of objects susceptible of physical interaction regardless of the intention of action of current action of the body (Ping, Dillon, & Beilock, 2009; Elder & Krishna, 2012; Eelen, Dewitte, & Warlop, in press), confirming previous hypotheses (Jeannerod & Frak, 1999). These mental simulations are greatly facilitated by cues of interaction such as suitably located handles or utensils (Elder & Krishna, 2012). Congruently with the focus of this study, Eelen and colleagues (in press) suggest that findings on mental simulations are relevant to online shopping. Rosa and Malter (2003) provide such an example, using a personalized mannequin in a website in order to encourage mental simulations of wearing the clothes. Given their results, the authors advise designers to use spatial features to support mental simulations in users.
Furthermore, as underlined by Elder and Krishna (2012), any kind of sensory experiences or actions could be simulated, given the relevant stimulus. For this reason, we argue that simulations of bodily movements could emerge from the perception of a moving environment embedded in a website.

We find support for the point of view of grounded cognition in Conklin, envisioning the future of information navigation in 1987: "The basic idea of hypertext, after all, is that ideas correspond to perceptual objects, and one manipulates ideas and their relationships by directly manipulating windows and icons." The idea of simulation of perceptual objects in already present in this early vision of an ideal information navigation modality.

The Present Study

In the present investigation, we asked participants to accomplish a searching task in a website containing a collection of books. We asked participants to locate multiple books in this website according to descriptions that we provided. The website was presented to each participant in either one of three versions, which differed in the modality of their navigation. One modality was standard hyperlinking, and as such consisted of loading a new web page after each click on a hyperlink. The other two modalities did not use hyperlinking and consisted of moving and scaling the contents of a single web page instead of opening new pages, and this was done either with or without animation. After the completion of the searching task on the website, participants were asked to complete again a similar searching task on the same website. We recorded the navigation behavior of participants as well as their success at the book location tasks.
From the basis of the hyperlinking modality, the two other modalities were designed to provide additional spatial cues at different levels, yielding three levels of spatial cueing: low, moderate, and high. The spatial cues were (a) spatial consistency, present in the moderate and high spatial cueing conditions, and (b) visual movement, present only in the high spatial cueing condition. Because the spatial cues were provided within the navigation modality itself (versus as an additional navigational aid), a split-attention effect (see Chandler & Sweller, 1992) was prevented from occurring.

Spatial consistency was achieved by having the contents of the website move and scale as a whole within a single page, instead of opening multiple pages like in hyperlinking. As a result, all elements were constantly in the same place in relation to each other, and navigation was possible without the use of a menu or any kind of semantic tool. Navigation with spatial consistency was similar to moving a camera or first-person point of view to different elements of the page. Although this metaphorical description of camera view was arguably relevant, it was not suggested to participants.

Visual movement was achieved by using an animation accompanying each navigation event in a website featuring spatial consistency. Navigation to and from the different elements of the page lasted a few moments, showing the elements of the page scale and move in real time. The navigation modality using visual movement in addition to spatial consistency was designed to provide the highest amount of spatial cueing.

Current research has shown that users navigate spatially in information systems due to the spatial nature of graphical browsers (Conklin, 1987; Dourish & Chalmers, 1994). We contend that disorientation and cognitive overload mainly arise
from spatial navigation because the spatial properties of information systems are too often volatile (Conklin, 1987), unless tied down by the use of a metaphor. We hypothesize that instead of employing a metaphor, spatial properties can be added with the effect of lowering disorientation and cognitive load because spatial properties provide the ability to generate mental simulations of movement (c.f. Barsalou, 2008).

Additionally, we argue that visual cues of movement can facilitate mental simulations (Elder & Krishna, 2012) and induce an egocentric perspective in mental simulation (Richter et al., 2000). If this is true, spontaneous and ego-centered simulations can promote an easier processing of the spatial dimension in navigation, reducing cognitive overload and disorientation.

Thus, we expect to find that the more spatial cues are provided to participants by the navigation modality, the more efficient and accurate participants will be at a searching task. We also expect to find that more spatial cues also induce faster navigation, leading to more navigation events within the same time span.

Also, we expect participants provided with more spatial cues to show a satisfactory level of navigation fluency even as novices. On the contrary, we expect participants provided with fewer spatial cues to suffer from disorientation. As suggested by Mayes, Kibby and Anderson (1990), disorientation in navigation may induce learning.

We hypothesize that participants in the low spatial cueing condition will compensate the difficulty of navigation by developing knowledge of the information system. As a result, we expect to find that the efficiency and accuracy of participants will improve more in conditions presenting fewer spatial cues.
In addition, we measured participants’s reading skills, spatial orientation skills, and visual memory skills. Because navigation relies on both semantic and spatial dimensions (Conklin, 1987; Dourish & Chalmers, 1994), we expect to find that participants with higher spatial orientation skills and participants with higher reading skills will show a better performance in terms of efficiency, accuracy, and speed of navigation. It is however to be noted that our materials contained written text and present a collection of books. For this reason, higher reading skills could lead to a higher navigation performance due to the nature of our materials, regardless of the semantic effects of reading skills on navigation. Also, we expect to find that participants with higher visual memory skills will show a better navigation performance in terms of efficiency, accuracy, and speed of navigation because it was argued that users of information systems also rely on a cognitive map for orientation (Boechler, 2001; McDonald & Stevenson, 1998; Nilsson & Mayer, 2002; Stanton et al., 1992; see also Toleman, 1948).

Finally, we measured participants’s experience after navigating the website presented to them, in terms of how easy participants found navigation was, and how participants enjoyed to navigate in the website. We expect to find that the better participants performed in terms of efficiency, the higher participants will rate the ease of use of the website. In addition, research has shown that the perceived ease of a task, defined as processing fluency, lead people to like the task more (Alter & Oppenheimer, 2009). For this reason, we expect to find that participants will report enjoying navigation more in a website that they rated easier to use.
CHAPTER II

LITERATURE REVIEW

Introduction

The theoretical background of this investigation begins with research on navigation in information systems. Navigation in information systems has shown to create disorientation and cognitive overload (Amadieu et al., 2009; Boechler, 2001). This is mainly due to the spatial dimension of hypermedia (Conklin, 1987). For this reason, we present research on mental representations of space. Findings indicating that ego-centered representations of space are central in orientation (Burgess, 2006) led us to explore the field of grounded cognition. The literature is presented here. The findings indicate that mental simulations are a core principle of cognition and affect perception, motion, judgment, and language (Barsalou, 2008).

Navigation in Information Systems

Navigation in computer-based information systems refers to the behavior adopted by a user when confronted with an information system. An information system can be composed of any type and any number of documents or media. Typical examples of computer-based information systems are websites, virtual encyclopedias, as well as other sets of interconnected documents.
Types of structures

Structures may take different forms. Amadieu and colleagues (2009) define two major types of information structures: hierarchical structures and network structures. In hierarchical structures, elements are linked according to their hierarchy in the system, and hierarchical cues are provided for navigation. Network structures don't have a hierarchical organization and can be considered less logical than hierarchical structures. McDonald & Stevenson (1996) used three different information structures in a study. The authors compared the abilities of participants to learn from a text in different structures. The first text had a hierarchical structure, the second text had a linear structure, and the third text had a network structure (described as “non-linear” in the original article). Participants performed better when using the linear structure as compared to the hierarchical structure. Also, participants performed better when using the hierarchical structure as compared to the network structure. In sum, the authors conclude that if a document cannot follow a linear structure, it is better to use a hierarchical structure.

Spatial dimension of hypermedia

In order to access the different elements and documents within the information structure, a mean of navigation must be provided. Research on navigation has been mainly focused on hypermedia navigation (also referred to as hyperlink navigation or hypertext navigation). Conklin (1987) describes that hypermedia navigation takes place within a graphical interface provided by a graphical browser and uses the user's spatial abilities to organize information in a two- or three-dimensional display. A crucial particularity of this is spatial environment is that users are in control of
their own navigation (Scheiter & Gerjets, 2007). Amadieu and colleagues (2009) detail this point of view, explaining that hypermedia navigation requires users to find their own path among many other possible paths. The same authors note that users are at times unable to determine what path they want to explore. For Boechler (2001) as well, one relevant aspect of cognition in hypermedia navigation is spatial processing. Spatial processing is relevant because the concept of space is used in order to describe hyperlink navigation. Also, users must remember their previous exploration, and at the same time assume the size, complexity, and architecture of the whole information structure, because the information structure can never be seen entirely at once. Conklin (1987) underlines as well the importance of users' spatial abilities as a key mechanism in hypermedia navigation.

The problem of disorientation

Conklin (1987) states that disorientation is a main issue in the use of hypermedia navigation. Amadieu and colleagues (2009) provide a definition of disorientation as a psychological state resulting from problems in connecting together the elements of an information structure and building a mental representation of the physical and conceptual space of the information structure. According to Scheiter and Gerjets (2007), disorientation is due to the fact that users are in control of their navigation in the information system. Boechler (2001) explains further that users suffer from disorientation when their spatial abilities do not allow them to process the complexity of the information structure and their own exploration of the structure. The same author
underlines that the problem of disorientation in hypermedia navigation has never been solved since the problem appeared in early computer-based information systems.

The problem of cognitive overload

Disorientation is found to be accompanied by another phenomenon, called cognitive overhead (Conklin, 1987; Boechler, 2001) or cognitive overload (Scheiter & Gerjets, 2007). This phenomenon is the cognitive state of an individual whose cognitive resources are insufficient to achieve a certain task or set of tasks. Conklin (1987) states that cognitive overload arises from hypermedia navigation because of the need for the user to remember their position in the information structure, and understand the whole structure simultaneously. In other words, cognitive overload has the same causes as disorientation. Scheiter and Gerjets (2007) describe that cognitive overload is caused by the cognitive tasks involved by hypermedia navigation, such as information selection and information sequencing. Furthermore, the same authors specify that the cognitive resources that are found to be insufficient and lead to cognitive overload are those related to spatial processing. A spatial task presented simultaneously with hypermedia navigation will create cognitive overload, but a non-spatial task presented simultaneously with hypermedia navigation may not create cognitive overload. Boechler (2001) states that cognitive overload is the cause of disorientation. Another consequence of cognitive overload described by Scheiter and Gerjets (2007) is that cognitive overload hinders learning in learning environments where the learner is in control, like in a hypermedia navigation system.
Variables affecting disorientation and cognitive overload

The type of information structure provided to the user was found to have an influence on disorientation and cognitive overload. Amadieu and colleagues (2009) studied the effects of different structures (hierarchical VS network) on learning, taking into account learners' prior knowledge of the material. The general results are that hierarchical structures are better suited for learners with low prior knowledge. They gain more conceptual knowledge with this structure, and suffer less mental effort and less disorientation. Learners with high prior knowledge also learned more from the hierarchical structure in this experiment but the effects on mental effort and disorientation were not found for this type of learner. For Amadieu and colleagues (2009), the hierarchical structure supports the generation of a cognitive map of the contents, which eases learning for learners with low prior knowledge.

In addition to prior knowledge and type of structure, the task and activity of the user of the information system also have effects on navigation and its efficiency. Benyon and Hook (1997) distinguish between the notions of “wayfinding” and “exploration” in navigation. The concepts can also be referred to as searching (for wayfinding) and browsing (for exploration). Searching is the activity of trying to locate or reach an element or information in the information system. Most research has been focusing on searching. On the contrary, browsing is the activity of navigating in an information system without trying to reach a particular element or find a specific piece of information. Browsing is the most relevant activity to acquiring a general understanding of an information system. When comparing the efficiency of searching and browsing on
a hierarchical structure VS a network structure, de Vries and de Jong (1997) found that network structures were more adapted to browsing behavior than for searching behavior. The authors also noted that hierarchical structures and network structures can be merged into a mixed structure. Like the hierarchical structure, the mixed structure was found to be better suited for searching.

Solutions to disorientation and cognitive overload

One cause of disorientation and cognitive overload is a discrepancy between a user's cognitive map or representation of the structure, and the implicit semantic structure of the information system (Chen, 1998). For this reason, it is important for users to have a correct cognitive map of the structure. For Chen (1998), the development of this cognitive map is based on the perception of landmarks. Then, route knowledge, which is the ability to navigate from one element to another element, can be acquired. The author underlines that, in order for this learning process to occur, the spatial relationships chosen by the designer must represent the underlying semantic structure intrinsic to the materials.

Hsu and Schwen (2003) argue that to solve navigational problems in hypermedia, structural cues must be provided to communicate what information is available, where the information is located, and how it is organized. The cues can come from text, but can also come from graphical presentations or metaphors. The authors defend that structural cues help developing a mental model of the system.

De Jong and van der Hulst (2002) provided structural cues in the form of a graphical overview representing the basic structure of the learning material that they
presented in hypermedia. They also provided some learners with hints and unobtrusive encouragements to follow the structure of the learning material. They found that participants who could use a visual overview learned more of the structure than other participants. The authors conclude that a visual display can improve learning of a structure, and that, as they found, this effect is independent from the exploration route taken in the material by the user.

Reviewing multiple studies, Chen (1998) concluded that structured navigation tools, in the form of maps or overviews, provide more help to novice users. However, for expert users, the navigation tools takes away the attention from the contents. Structured navigation tools are thus advised for novices. In conclusion, the author suggested guidelines to provide support to both novice and expert users, but using different features for each of them. No solution was provided to help navigation regardless of users' prior knowledge.

Another way to provide structural cues is the use of metaphors (Benyon and Hook, 1997; Hsu and Schwen, 2003). The spatial dimension of the information system itself is actually referred to as a metaphor by Boechler (2001). The author describes this metaphor as the referent metaphor in navigation. However, the author underlines that this metaphor lacks attributes of the object it refers to, that is, physical space. For example, the distance between two elements of an information structure cannot be measured in any unit like distances are measured in meters in the physical world. Boechler (2001) argues that the spatial metaphor is not a given when it comes to computer-based information systems, and that its relevance has limits, creating metaphor mismatches. This also
relates to the argument of Dourish and Chalmers (1994) that designers should not rush towards using spatial models although they have positive capabilities and useful properties.

More elaborate metaphors have been used in information spaces to provide structural cues. Hsu and Schwen (2003) studied two different metaphors: the book metaphor and the folder metaphor. The metaphors were page layouts, contents lists and folder labels, among others. Three conditions of navigation were created, one with minimal metaphorical cues, a second with metaphorical cues issued from one metaphor only, and a third condition with metaphorical cues issued from both metaphors. The participants of this study had to complete a search task using either one of the three conditions of navigation. The results showed that participants in the condition that provided more metaphorical cues were more accurate in the searching task that participants in other conditions. However, no results were found regarding speed, navigational behavior, and satisfaction.

One drawback of metaphors in general is noted by Benyon and Hook (1997), who suggest that metaphors should not import limitations of the real world into the virtual world. Another interesting look at metaphor is this of Dillon and colleagues (1990), who underlines the difference between the emulation of a referent and the retention of its useful structures. For example, emulating of a book would involve replicating the grain of the paper, the curving movement of pages when they are turned, etc. A metaphor can be created simply by retaining the relevant structures. A limit has to be drawn between emulations and parsimonious metaphors.
Mental Representations of Space

Toleman was the first to coin the term "cognitive map". In 1948, he published a paper summarizing his work on lab rats. He had studied the behavior of rats in mazes and the improvement of their ability to move through repeatedly presented mazes. Rats learned how to cross mazes. However, Toleman argued that rats did not develop simply a knowledge of the correct path to the food placed on the other side of the maze, but that rats developed a cognitive map of the labyrinth. Toleman showed that when mazes were modified, rats would choose to explore pathways the lead most probably to the food they had located according to the actual map of the maze, rather than choosing pathways similar or close to the path that used to guide to food. Toleman generalized these findings to human beings, arguing that people develop cognitive maps like rats do and that people use these maps for orientation.

Franklin and Tversky (1990) measured participants's response times to identification of the location of objects in space in comparison to an observer placed in various positions. The authors found from their results that some axes of the body were more readily available and led to shorter response times. These axes of the body were dependent on the position of the body in the environment, and stemmed from the possibility of action in these axes, indicated by the possibility of limbs movement. The authors reject the idea that spatial locations are processed evenly across all axes of spaces, and reject also the idea that spatial locations processing is a linear function of the angle separating the object from the front axis of the individual.
Klatzky (1998) reviews various studies on allocentric and egocentric representations of space. Allocentric representations are defined as representations seen from an external point of view, like a map. Egocentric representations are defined as representations seen from the perspective of the self. Klatzky notes that different movements allow or not to update one's egocentric representation. Updating one's egocentric representation is also possible in imagination, in the case of translations, but not in the case of rotations. The author argues that proprioceptive information is necessary to cognitively manage changes in angular position, regardless of the type of representation used (egocentric or allocentric).

Wang and Spelke (2000) defend that spatial orientation is supported only by egocentric representations, as opposed to allocentric representations. The authors argue against the idea that people use cognitive maps, and suggest that people are simply capable of considering the position of many targets while they move, continuously updating the positions of targets during locomotion. However, Mou, McNamara, Valiquette, and Rump (2004) found that spatial references were not updated during locomotion.

For Burgess (2006), egocentric and allocentric representations exist in parallel. The author describes that at every moment, only one representation system is generally used, although the two systems can be used simultaneously. The representation system used varies with locomotion, structure of the environment, and experience of the environment.
Grounded Cognition

Barsalou (1999) presents the theory of perceptual symbol systems (PSS). In this theory, cognition is based on perception. PSS theory states that the brain captures the sensory activation and stores it as a neural activation pattern. Later, when the same pattern is activated, recognition or recall occurs. The activation of the neuron pattern can be due to external stimuli or internal stimuli. Internal stimuli used in the reactivation of patterns are mental simulations. Mental simulations can be covert, below consciousness threshold level, or overt, like when one pictures a scene visually in their mind. For Barsalou, the simulations are a basic process of cognition, allowing not only perception and memory but also more complex processes. Barsalou defends that the PSS theory explains cognition with more parsimony than most other cognitive models, because most cognitive models require amodal symbols. These symbols have never been proven to exist, according to Barsalou. Grounded cognition, however, explains cognition on the base of neural activation patterns. Barsalou provides in this paper a great amount of support to the PSS theory.

In 2008, Barsalou publishes another theoretical article, defending the theories of grounded cognitions altogether. Barsalou presents the origins of grounded cognition, and all the elements in common between the different theories. Once again, the emphasis is placed on demonstrating the parsimony of grounded cognition against other cognitive theories.

Eelen, Dewitte, and Warlop (in press) bring support to embodied cognition by demonstrating that the orientation of a product on an advertisement influence consumers.
More specifically, the adequation between a participant's most available or favorite hand with the orientation of the handle of a product on a picture makes the product more reachable, and leads participants to covertly simulate the action of grabbing the object. As a consequence, the positive or negative affects related to a product are enhanced or hindered if the orientation is respectively adequate or inadequate. Eelen and colleagues conclude that mental simulations automatically occur in people's interaction with their environment, and are a basic process of cognition. These results build on previous similar research conducted by Elder and Krishna (2012) leading to identical conclusions.

Ping, Dhillon, and Beilock (2009) also came to the conclusion that perceiving an object led to automatic covert motor simulations of an action on this object. The authors argue that the simulation is helpful in decision making because of processing fluency. A simulation that is easier to generate will lead to liking more the corresponding action. As a consequence, this action will preferably be performed. As a consequence, a non-acting motor system still uses bodily simulations to interact with the environment, as a basic modality of cognition. It affects perception as well as decisions.

Goldberg, Perfetti, and Schneider (2006) used neuroimagery to show that knowledge retrieval involved the activation of brain regions related to the sensory modality of the specific knowledge. This suggests that knowledge recovery and perception share a common neural basis.

Matlock (2004) found that metaphorical sentences involving the description of movement lead to mental simulations. The details of the sentence affected the mental simulations of movement, according to constraints of the physical world. The author
argue against amodal approaches of language, and suggests that language is based on
mental simulations at least in some part.

Richardson, Spivey, Barsalou, and McRae (2003) found similar results in a
study on language. They showed that comprehension of words interacted with the motor
system, even when the word did not describe movement. The authors argue that these
results demonstrate the perceptual-motor character of linguistic representations and
underline that their results support Barsalou's (1999) PSS theory.

Reimann and colleagues (2012) support that emotions are both a bridge
between perceptions and cognitive processing and perceptions. They propose the somatic
marker theory from Damasio (1994) as a unifying conceptual framework for embodiment
in judgment and choice. For them, mental simulations can have the same effects as a
body movement. Reimann and colleagues (2012) also suggest that future research should
take into account theories of metaphor into embodiment research.

For Niedenthal and colleagues (2009), embodied cognition is not only present
in motor-driven processes, but also in sensory-driven processes. In four complementary
studies, the authors found that emotion concepts can be internally simulated in
participants exposed to relevant stimuli. The simulation is not only a mental process but
also a bodily process, since artifacts of embodied cognition are detected in the muscle
activity of the participants. In Niedenthal and colleagues's experiments, participants were
asked to process emotionally charged words. In one condition, the task of participants
was relevant to emotions; in a second condition, the task of participants was relevant to
the form of the material and not to the emotional contents. Although exposed to the same
material, only participants who had to process emotional contents displayed the facial muscular activity that corresponded to the word processed. Niedenthal and colleagues (2009) concluded that this recorded muscular activity was the trace of embodied cognition and of the modality-specific processing of the emotion. To confirm this hypothesis, in another experiment, they prevented the muscular activity to happen by having the participants hold a pen in their mouth. They were less capable of processing emotion concepts: they performed more poorly at defining the words as emotionally charged or not emotionally charged. One last result of Niedenthal and colleagues' experiments was that the artifacts of mental simulation are only present when relevant for the task. The use of a metaphor could make screen movements more salient as virtual body movements, and thus induce effects from embodied cognition.

Niedenthal and colleagues (2005) support Barsalou's (1999) Perceptual Symbol Systems (PSS) embodiment theory. The authors compare the PSS theory to other theories under the light of previous criticism. The authors indicate that approach-avoidance effects are examples of embodied cognition. They also emphasize the fact that embodiment does not only take place online, that is, when the body is actually moving or changing. Embodiment also takes place offline, when a participant is simply thinking about an object. When happening offline, the embodiment is called a simulation and is used in cognition to process, for example, external stimuli. These results complement those of Niedenthal and colleagues (2009).

Basing their work on embodiment, Rosa and Malter (2003) note that the perception of spatial dimension in websites cannot be controlled by web designers
because they can not change the user's physical environment. The authors suggest that designers should lead the users to internally simulate the experience of the product that they are exploring by using spatial features. They give the example of a personalized mannequin wearing clothes for the website user in order to encourage mental simulation of wearing the clothes. They also advise to use animations to provide a spatial environment more salient than the physical environment present around the website user, and use this provided environment to induce perceptual simulations. The authors advocate that what they exemplify with clothing should be applied as well to a variety of goods. They also suggest that embodiment can play a key role in purchases, even if the buyers would rationalize with a more socially accepted reason for their choice. In other words, they might invoke a technical advantage of the product as the reason of their purchase, while the actual cause might be anchored in their embodied cognition.

Labroo and Nielsen (2010) derived the idea of their study from a method in clinical psychology in which patients mentally approach the object of their phobia in order to cure it. The thesis defended by Labroo and Nielsen (2010) is that approaching any object will lead to a more positive attitude towards this object. They define the bodily approach sensation as embodied cognitions that stemmed from a movement that could be physical or psychological, spatial or temporal, and that was directed towards an object. Three questions were asked by the authors. Firstly, they wanted to know if this principle would apply to objects that the participant disliked, that is, towards which they had negative attitudes. Secondly, the authors wondered if the change towards a more positive attitude would transfer to related objects. Thirdly, the authors asked if the
physical bodily movement is necessary to lead to the out-coming change in attitude, or if a mental simulation would be sufficient. The results of three experiments confirmed the three hypothesis. This effect only worked if participants were not aware that the approach effect was the cause of the liking. The authors warned of a possible contrast effect in mentally approaching objects of negative attitude, leading to more disliking due to a feeling of conflict. However, they did not find this effect in their three experiments.
CHAPTER III

METHODOLOGY

Design

One factor, Spatial Cueing, was varied in three versions to yield three between-participants experimental cells. The resulting design was a 3 Spatial Cueing (High Spatial Cueing vs. Moderate Spatial Cueing vs. Low Spatial Cueing) fixed analysis of variance.

Participants

One hundred and thirty-three undergraduates volunteered for participation (61 percent female, 39 percent male) and were randomly assigned to either the high, moderate, or low spatial cueing condition, respectively. Participants ranged in age from 18 to 53 years ($M = 21.52, SD = 3.98$). Eighty-one percent reported English to be their first language, with the remaining 19 percent reporting English to be their second language.

Experimental Materials

The experimental materials employed in this investigation included three experimental websites, two booklets containing task instructions, a measure of reading skills, a test of spatial orientation skills, a test of visual memory skills, a demographic
questionnaire, and a measure of user’s perceived experience after navigating one experimental website.

Experimental Websites's Contents and Structure

Three different experimental websites were created for the purpose of the study. The contents of all three websites were identical and consisted of an assortment of 100 books provided by the editor of the books. All books were part of the same collection, written for teenagers with low reading abilities. For this reason, the books were written in simple English. The covers of the books always consisted of a title and a picture. The picture was a color drawing relevant to the theme of the book. Additionally, each book belonged to either one of five genres, and 20 books belonged to each genre. The five genres were adventure, mystery, sports, education, and biographies. However, the genres were always represented by a colored logo, and the name of the genres was never written. The logos were depicted as: a red compass logo for adventure, a purple question mark logo for mystery, a green football logo for sports, a yellow columned facade logo for education, and a brown portrait logo for biographies.

The structure of the websites was designed as information nodes connected to each other with a two-way structural relationships. The structure of the material (books belonging to genres) led to designing the websites with a hierarchical structure. The hierarchical structure was given three levels: top level, genre level, book level. The top level contained only one structural node, the genre level contained five structural nodes, one for each genre, and the book level contained 100 structural nodes, one for each book. The top level node was connected to each of the five genres. Each genre was connected
to each of the 20 books contained in the genre. Consequently, the top level was connected to each book through one of the five genres.

In addition to the hierarchical structure, a network structure was added to the website, creating a mixed structure as described by de Vries & de Jong (1997). The network structure consisted of structural relationships within each hierarchical level. The top level contained a single node, thus no additional structural relationship could be added within this level. At the genre level, each of the genres was connected to either one or two other genres. As a result, each of the genres was connected to the other four genres through a network of structural relationships. Similarly, at the book level, each book was linked to either three, five, or eight books that belonged to the same genre. As a result, within the same genre, each book was linked to all other 19 books of this genre through a network of structural relationships. A simplified schema of the structure is presented in Figure 1, showing only a four-books sample for clarity. Red arrows represent hierarchical structural relationships, green arrows represent structural relationships issued from the network.

**Experimental Website Operationalizing Low Spatial Cueing**

Following the structure described above, an experimental website was created to operationalize low spatial cueing. This website contained 106 web pages. One web page was created for each book, one web page was created for each genre, and one web page was created for the top level, creating one web page per node of the information structure. Each web page contained a main section covering the top ¾ of the page and a menu section covered the bottom ¼ of the page.
At the top level, one web page was created. This page presented the five genre logos displayed next to each other, horizontally aligned in the center of the screen. The size of the logos was approximately four centimeters; the spacing between the logos was approximately one centimeter. Each logo was hyperlinked to the page of the corresponding genre, at the genre level. The menu section of this page was empty because this page was only connected to each genre, accessible in the main section.

Figure 2 presents a screenshot of the top level web page extracted from this website.

At the genre level, each web page contained a thumbnail picture of each book cover that pertained to this genre, adding up to a total of 20 thumbnail pictures per web page. The thumbnail pictures were displayed in four rows of five thumbnail pictures, in the center of the screen. The size of the thumbnail pictures was approximately two centimeters by three centimeters; the spacing between the thumbnail pictures was
approximately a quarter of a centimeter. Each thumbnail picture was hyperlinked to the web page of the corresponding book, at the book level. In the menu section, a first line contained hyperlinks to the other genres that this genre was connected to according to the information structure. These hyperlinks were presented in the form of logos, measuring approximately 1.5 centimeters. A second line of the menu contained a hyperlink to the top level, represented as a composite logo consisting of all five genre logos overlapping each other, measuring approximately 5 centimeters by 1.5 centimeters. Figure 3 presents a screenshot of a web page at the genre level extracted from this website.
At the book level, each page contained a picture of the book cover displayed in the center of the screen. The size of the picture was approximately 10 centimeters by 15 centimeters. A button present at the bottom of the book cover allowed a user to display and hide an excerpt of the corresponding book. When displayed, the excerpt was located on the book cover, covering approximately the bottom half of the book cover.

The excerpt consisted of a text passage extracted from the corresponding book, presented in black font on a semi-transparent white background. The length and the reading level of the excerpt varied according to the book. Lengths ranged from 72 words to 97 words.
(M = 81.80, SD = 4.59). Reading levels ranged from 1st to 3rd grade (M = 1.9; SD = .72). At the bottom of the text excerpt, a check box and another button were present. The check box was accompanied by the text “This is the book that I am looking for!”. The button was accompanied by the label “Confirm”. The check box and the button were designed to allow for users to make a selection of the book they were asked to find. In the menu section, a first line contained hyperlinks to the other books that the selected book was connected to according to the information structure. These hyperlinks were presented in the form of book cover thumbnail pictures identical to the thumbnail pictures used in the main section of genre web pages. A second line of the menu
contained a hyperlink to the genre the selected book belonged to, represented as a logo identical to the logos used in the menu section of genre web pages. Figure 4 and 5 present screenshots of a web page at the book level extracted from this website, with the excerpt (Figure 4) and without the excerpt (Figure 5).

This website was considered to be an operationalization of low spatial cueing because spatial continuity was broken during navigation. Indeed, elements first located in the main part of the screen would be located in the menu part in another page. Also, elements located next to each other in the main part of the page would not necessarily be
located next to each other when displayed in the menu. This website was designed with the intention to reproduce a standard website hypermedia navigation, without additional spatial cueing.

Experimental Website Operationalizing High Spatial Cueing

The second experimental website that was created operationalized high spatial cueing. This website consisted of a single page. The same contents and structure were used as in the website operationalizing low spatial cueing, but a different navigation modality was used. In the website operationalizing high spatial cueing, the selection of an element with a mouse click did not open a new page, but centered and scaled the whole website around the selected element. The process of centering and scaling lasted 600ms.

Because this website consisted of a single page, this website did not include a menu. Thus, the single page of this website consisted of the pictures of the 100 book covers, presented in five groups of 20 book covers, each group corresponding to one genre. The groups were horizontally aligned in the center of the screen. In each group, the pictures were organized in four lines of five pictures. In the prime state of the website, before any scaling or centering took place, the pictures measured approximately \( \frac{3}{4} \) centimeter by \( \frac{1}{2} \) centimeter and were separated by a millimeter. The groups measured approximately five centimeters by five centimeters and were separated by \( \frac{1}{4} \) centimeter. A blur effect was also added on each group to ensure that the books covers could not be individually identified before navigating to the genre level. Additionally, the logo of the corresponding genre was added in the center of each group, and was not blurred. The
logos measured approximately two centimeters. This state of the web page was visually very similar to the top level page in the website operationalizing low spatial cueing. The only differences were the presence or absence of a menu at the bottom of the page and the presence or absence of the blurred pictures of the book covers behind the genre logos. Figure 6 presents a screenshot of the website operationalizing high spatial cueing, in its prime state, when the top level is selected.

In this website, when a genre was selected by clicking on the corresponding group of pictures or logo, the entire page was scaled and the group of pictures was centered on the screen. The logo of the genre disappeared, as well as the blur effect on

![Figure 6. Top Level Web Page with High Spatial Cueing](image-url)
the pictures. The elements that remained visible were the book cover pictures belonging to the selected genre, and a part of the blurred groups of pictures representing genres that were spatially located next to the selected genre, either on the left or on the right of the page. Clicking on the groups of pictures corresponding to other genres allowed a user to navigate to them. In addition, navigation to the top level was possible by clicking on the background of the page. In this state of the web page, the size of the book cover pictures was approximately two centimeters by three centimeters and the spacing between the pictures was approximately a quarter of a centimeter. This state of the web page was visually very similar to a page of the genre level of the website operationalizing low spatial cueing. The two websites differed in the presence or absence of a menu at the bottom of the page and the presence or absence of partially displayed groups of cover pictures next to the central element. Figure 7 presents a screenshot of the website operationalizing high spatial cueing, when a genre is selected.

In this website, when a book was selected by clicking on the corresponding cover picture, the page was scaled and centered on the selected cover picture. Additionally, a button controlling the display of an excerpt of the book appeared at the bottom of the book, and had the same properties as the similar button created for the website operationalizing low spatial cueing. Cover pictures that were located next to the selected cover picture were still partially visible. Clicking on these pictures allowed a user to navigate to them. Additionally, navigation to the genre level was possible by clicking on the background of the page. In this state of the web page, the size of the cover picture was the same as in book level pages of the first website. Once again, this
The state of the web page was visually very similar to a page of the book level in the website operationalizing low spatial cueing. The two websites differed in the presence or absence of a menu at the bottom of the page and the presence or absence of partially displayed cover pictures next to the central element. Figure 8 and 9 present screenshots of the website operationalizing high spatial cueing, when a book is selected, with the excerpt (Figure 8) and without the excerpt (Figure 9).

This website was considered to be an operationalization of high spatial cueing because spatial continuity was maintained during navigation. Indeed, all elements
remained in the same position relative to each other throughout navigation. Additionally, the duration of the spatial transformations of centering and scaling operated by the computer allowed the perception of movements, namely zooming in, zooming out, and horizontal and vertical movements. This website was designed with the intention to include two types of spatial cues, spatial continuity and visual movement, without conveying additional limitations.

The last experimental website created operationalized moderate spatial cueing. This website was identical in form and structure to the website operationalizing

*Figure 8. Book Level Web Page with High Spatial Cueing, Excerpt Absent*
high spatial cueing, except for one parameter. The modified parameter was the duration of scaling and centering of the page; it was set to zero milliseconds. Consequently, this website was considered to be an operationalization of moderate spatial cueing because spatial continuity was maintained, although movements like zooming and horizontal and vertical movements could not be perceived. Thus, this website constituted an intermediate condition between the high spatial cueing and low spatial cueing conditions.
**Booklets containing task demands**

Two different booklets were created in order to convey the task demands. Each of them contained the descriptions of twenty different books that were present in the experimental website, organized as a numbered list with one description per page of the booklet. The length of each description ranged from 13 words to 24 words ($M = 18$, $SD = 3.27$). Each description consisted of two parts. The first part described information that could be found from the title or the cover art of the corresponding book. The second part described information that could only be found in the excerpt of the corresponding book.

**Navigation Practice Page**

A practice page mimicking the experimental website navigation was designed in three different versions corresponding to the three experimental conditions and built with the corresponding tools and technologies. The practice page consisted of two colored squares—one red and one green—placed inside of a gray container. The container mimicked a genre from the experimental website; each of the squares mimicked a book from the experimental website. A feedback message appeared on each square when a user successfully navigated to it.

**Measure of reading skills**

A measure of reading skills was created by using a curriculum-based measurement (CBM) technique, namely the maze task. The reading test consisted of a text passage containing 304 words, at a Flesch-Kincaid reading level of 2.3. The passage was extracted from a book issued from the same collection as the books presented in the experimental website. The first sentence of the passage was kept unchanged. After the
first sentence, every seventh word was replaced by a test item. The item consisted of the 
original word randomly placed before, after, or between two distractor words. The three 
words composing the item were colored in blue and bolded to make them salient. The 
instructions of the task indicated to select with the mouse, for each test item, the original 
word among the distractors. A reading ability score was calculated as the total number of 
original words located among the distractors. The duration of the test presentation was 
one minute. The administration of this test followed the CBM administration guidelines 
provided by Fuchs and Fuchs (2007). Wayman and colleagues (2007) reviewed the 
research on CBM in a literature synthesis and underlined the robustness of CBM 
measures across different text bases. Furthermore, the maze task was shown to measure 
multiple dimensions of reading and to be a good index of comprehension (Fuchs & 
Fuchs, 1992).

Test of spatial orientation skills

    A test of spatial orientation skills, the card rotations test, was taken from the 
consisted of two pages containing ten items each. Each item consisted of one drawn 
figure serving as a referent and eight similar figures meant to be compared to the referent. 
The task was to determine if each figure was the same as or different from the referent. A 
figure that was a rotated version of the referent but was identical to it in its other aspects 
was defined as being the same as the referent. A figure that was a modified version of the 
referent in any aspect except for rotation (e.g., symmetry) was defined as being different. 
Each page of ten items was presented for three minutes. The total score on this test was
determined by subtracting the total number of errors from the total number of good answers. The possible scores ranged from -160 to +160 with a chance score of 0. The reliability of the measure was assessed with a split-half method between the two pages of ten items each. The measure had a Spearman-Brown reliability coefficient of .94. A practice page consisting of three items, presented for one minute, preceded the test.

**Test of visual memory skills**

A test of visual memory skills, the map memory test, was taken from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, & Harman, 1976). The test consisted of two parts. Each part consisted of a map with streets and buildings, and of a following answer page where a similar map was presented, but where the buildings were replaced by letters ranging from A to E. Twelve test items were present next to the map on the answer page, in the form of the previously presented buildings. Each item was accompanied by an array of letters ranging from A to E. Selecting the letter corresponding to where the building was located on the map was scored as a correct answer; selecting another letter was scored as a wrong answer. In each part, both the map and the answer page were presented for four minutes. The total score on this test was determined by subtracting a quarter of the total number of errors from the total number of good answers. The possible scores ranged from -6 to +24 with a chance score of 0. The reliability of the measure was assessed with a split-half method between the two parts of twelve items each. The measure had a Spearman-Brown reliability coefficient of .73. A practice consisting of a map containing three buildings, presented for one minute, and the corresponding answer page, presented for one minute as well, preceded the test.
Demographic questionnaire

A demographic questionnaire consisted of multiple choice questions pertaining to the age and gender of participants, their three primary languages, the number of years they had spent in college, where they usually bought books, and how many hours they generally spent on-line in a day, as well as a 7 point Likert scale pertaining to how much they enjoyed reading for leisure (1=“do not enjoy at all”; 7=“enjoy a lot”).

Measure of user experience

Two declarative measures of user experience were employed on 7 point Likert scales presented on the computer. One measure asked how easy participants found navigating the website (1=“not easy at all”; 7=“very easy”), and the other measure asked how much they enjoyed navigating the website (1=“did not enjoy it at all”; 7=“really enjoyed it”).

Procedure

Participants entered a computer lab on campus and were randomly directed to prepared computer stations. On the computer, the experimental materials were presented as HTML pages and displayed with a web browser in kiosk mode. This mode displayed the pages in full screen, hid the web browser's navigation buttons, and prevented participants from leaving the window of the experiment.

Participants were first asked to read an informed consent on the computer screen and to click on a radio button to indicate their agreement with the informed consent, before being given explicit instructions about their task. The informed consent
was also read aloud to them by the experimenter. Then, participants were asked to view and follow instructions pertaining to the various tasks of the study on the computer screen. All instructions were also read aloud by the experimenter. Participants progressed from page to page by clicking on a link with the mouse when the experimenter indicated to do so. Participants were not allowed to move ahead in the website until all participants were on the same page.

After a first set of instructions, participants reached a navigation practice page corresponding to the condition to which they were assigned. Participants could access the next page only after all participants were capable of proficient navigation. The experimenter provided help when necessary.

After the navigation practice page a page of instructions followed, prescribing the search task to perform on the experimental website. Participants were instructed to locate in the website as many of the books described in the first booklet as possible. The time limit of the search task was ten minutes and was indicated to participants. Then, the experimental website was presented.

After the experimental website, the measure of reading skills was presented, along with relevant instructions. Following the measure of reading skills, the experimental website was presented again, preceded by the instruction to locate in the website as many of the books described in the second booklet as possible, and the indication of the time limit of the task of 4 minutes. After the experimental website, participants completed the demographic questionnaire on the screen, followed by the measure of user experience. Finally, the test of spatial orientation skills and the test of
visual memory skills were administered to participants in this order. At the end of the procedural sequence, participants were thanked, debriefed and excused.
CHAPTER IV

RESULTS

Data Source

A JavaScript program recorded all navigation behavior in the experimental websites. Each click on an element of the website was tracked. The program provided for each section the number of books selected as task targets, the number of correct selections and the number of errors, and the number and direction of all navigation events.

For each of the two sessions, a score of efficiency was calculated by subtracting the number of errors from the total number of books selected, providing the number of books properly located in the limited time span of the session. A score of efficiency improvement was calculated by first estimating expected efficiency in the second session on the basis of efficiency in the first session, and then subtracting expected efficiency from observed efficiency in the second session. A score of accuracy for each session was created by dividing the number of errors by the total number of books selected. A score of accuracy improvement was calculated using the same method as described above. A score of network navigation was created by counting navigation events happening within the same structure level. Similarly, a score of hierarchical navigation was created by counting all navigation events happening between different
structure levels. Scores of network navigation improvement and hierarchical navigation improvement were also calculated using the same method as described above.

The measure for reading skill proficiency was the sum of the number of words correctly selected in the test items. The measure for visual memory and spatial orientation skills were the scores provided by the specific grading procedure for each corresponding test.

Finally, all measures were tested in variations of the basic experimental design and accepted as statistically significant if the alpha level was below .05.

Analysis of Navigation Behavior

Relations between measures

In order to determine the relations between the different measures of navigation behavior, a series of Pearson correlation analyses across conditions was conducted. Considering both sessions together, a significant correlation was found between accuracy and efficiency, $r(129) = .51, p < .001$, as well as between network navigation and hierarchical navigation, $r(133) = -.34, p < .001$ (Table 1). These results indicate that participants who found more books also committed fewer errors and that participants who used more hierarchical navigation used less network navigation. Also, a significant correlation was found between efficiency and reported navigation ease, $r(133) = .26, p = .003$, as well as between reported navigation ease and reported navigation enjoyment, $r(133) = .48, p < .001$ (Table 2). These results indicate that participants who found more books reported navigation in the website to be easier, and
that participants who reported navigation to be easier reported enjoying navigation to a higher degree.

Table 1. Correlations Between Navigation Behaviors

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<td>.505</td>
<td>.035</td>
<td>.141</td>
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<td>.686</td>
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<tr>
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<td>Sig. (2-tailed)</td>
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</tr>
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<td>-.338</td>
<td>1</td>
</tr>
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<td>Sig. (2-tailed)</td>
<td>.686</td>
<td>.967</td>
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<td>133</td>
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Effects of participants' skills

In order to assess the hypotheses that participants' reading skills, spatial orientation skills, and visual memory skills affected navigation behavior, a series of Pearson correlation analyses across conditions was conducted. Considering both sessions together, reading skills were found to be significantly correlated to efficiency, $r(133) = .31, p < .001$, hierarchical navigation, $r(133) = .21, p = .015$, and network navigation, $r(133) = .20, p = .021$ (Table 2). This indicates that higher reading skills lead participants to locate more books and use more both hierarchical and network navigation. Also, spatial orientation skills were found to be significantly correlated to efficiency,
These results indicate that higher spatial orientation skills lead participants to locate more books, use more network navigation, and make less errors relatively to the number of books selected. Visual memory skills failed to have significant effects on either efficiency, accuracy, hierarchical navigation, or network navigation, $p > .05$ in all cases (Table 2).

In addition, the same series of correlations analyses was performed again separately for first and second session. The correlations were then compared using Fisher $r$-to-$z$ transformations, but no significant differences were found between the correlations of the two sessions. This suggests that the skills of the participants influenced navigation consistently across the two sessions.

Finally, spatial orientation skills and reading skills were found to be significantly correlated to each other; $r(131) = .22$, $p = .011$, indicating that participants

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<tr>
<th></th>
<th>Efficiency</th>
<th>Navigation Ease</th>
<th>Navigation Enjoyment</th>
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<td>Sig. (2-tailed)</td>
<td>133</td>
<td>133</td>
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<tr>
<td></td>
<td>N</td>
<td>133</td>
<td>133</td>
</tr>
<tr>
<td>Nav. Ease</td>
<td>Pearson Correlation</td>
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<td>Sig. (2-tailed)</td>
<td>.003</td>
<td>133</td>
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<tr>
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<td>133</td>
<td>133</td>
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<td>Nav. Enjoy.</td>
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<td>.478</td>
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<td>N</td>
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$\rho(131) = .35$, $p < .001$, accuracy, $\rho(127) = .29$, $p = .001$, and network navigation, $\rho(131) = .25$, $p = .004$ (Table 2). These results indicate that higher spatial orientation skills lead participants to locate more books, use more network navigation, and make less errors relatively to the number of books selected. Visual memory skills failed to have significant effects on either efficiency, accuracy, hierarchical navigation, or network navigation, $p > .05$ in all cases (Table 2).
Table 3. Correlations Between Skills and Navigation Behaviors

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<tbody>
<tr>
<td>Reading Skills</td>
<td>Pearson Correlation</td>
<td>.310</td>
<td>.113</td>
<td>.210</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.204</td>
<td>.015</td>
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<tr>
<td></td>
<td>N</td>
<td>133</td>
<td>129</td>
<td>133</td>
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<tr>
<td>Spatial Rotation Skills</td>
<td>Pearson Correlation</td>
<td>.350</td>
<td>.287</td>
<td>-.005</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.001</td>
<td>.955</td>
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<tr>
<td></td>
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<td>131</td>
<td>127</td>
<td>131</td>
</tr>
<tr>
<td>Visual Memory Skills</td>
<td>Pearson Correlation</td>
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<td>-.052</td>
<td>.108</td>
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<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.970</td>
<td>.558</td>
<td>.217</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>132</td>
<td>128</td>
<td>132</td>
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</table>

with higher spatial orientation skills also had higher reading skills, and vice-versa (Table 4).

These results together show that reading skills and spatial orientation skills had an effect on navigation behavior, but visual memory skills failed to have such effect. The effects of reading skills and spatial orientation skills on navigation behavior was taken into account in further analyses.

Effects of conditions on efficiency

In order to assess the effects of spatial cueing on efficiency, a one-way fixed analysis of variance (ANCOVA) of spatial cueing was conducted on efficiency for the first session, with reading skills and spatial orientation skills as covariates. The analysis yielded significant variations among spatial cueing, $F(2,126) = 9.13, p < .001, \eta = .36$. A post-hoc Bonferroni test indicated that efficiency in the high spatial cueing condition
(M = 5.60; SD = .24) was significantly higher than in both the moderate spatial cueing condition (M = 4.27; SD = .25), p = .039, and the low spatial cueing condition (M = 4.14; SD = .25), p < .001. Moderate spatial cueing failed to differ significantly from low spatial cueing (Figure 10).

However, a second ANCOVA of spatial cueing on efficiency for the second session with reading skills and spatial orientation skills as covariates did not indicate a significant effect of spatial cueing.

In order to determine if efficiency varied differently for each condition between the first and the second session, a one-way ANCOVA of spatial cueing was conducted on efficiency improvement, with reading skills and spatial orientation skills as covariates. The analysis yielded significant variations among spatial cueing,

Table 4. Correlations Between Skills

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<tr>
<th></th>
<th>Reading Skills</th>
<th>Spatial Rotation Skills</th>
<th>Visual Memory Skills</th>
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<tbody>
<tr>
<td></td>
<td>Correlation</td>
<td></td>
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<tr>
<td>Reading Skills</td>
<td>Pearson Correlation</td>
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<td>.221</td>
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<tr>
<td></td>
<td>Sig. (2-tailed)</td>
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<td>.011</td>
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<td>131</td>
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<tr>
<td>Spatial Rotation Skills</td>
<td>Pearson Correlation</td>
<td>.221</td>
<td>1</td>
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<tr>
<td></td>
<td>Sig. (2-tailed)</td>
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<td>.011</td>
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<td>N</td>
<td></td>
<td>131</td>
</tr>
<tr>
<td>Visual Memory Skills</td>
<td>Pearson Correlation</td>
<td>-.132</td>
<td>.086</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
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<td>.131</td>
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A post-hoc Bonferroni test indicated that efficiency improvement in the low spatial cueing condition ($M = .56; SD = .20$) was significantly higher than in the high spatial cueing condition ($M = -.16; SD = .20$), $p = .038$. Moderate spatial cueing ($M = .02; SD = .21$) failed to differ significantly from spatial cueing that was either high or low (Figure 11).

**Effects of conditions on accuracy**

In order to assess the effects of spatial cueing on accuracy, a one-way fixed analysis of variance (ANCOVA) of spatial cueing was conducted on accuracy for the first session, with reading skills and spatial orientation skills as covariates. The analysis
yielded significant variations among spatial cueing, $F(2,126) = 3.44$, $p = .035$, $\eta = .23$. A post-hoc Bonferroni test indicated that accuracy in the low spatial cueing condition ($M = .82; SD = .03$) showed a tendency to be lower than in both the high spatial cueing condition ($M = .91; SD = .03$), $p = .065$, and the moderate spatial cueing condition ($M = .91; SD = .03$), $p = .083$. Accuracy in high spatial cueing and moderate spatial cueing conditions was found practically identical (Figure 12).

In addition, a similar ANCOVA of spatial cueing on accuracy for the second session also indicated a significant effect of condition, $F(2,122) = 4.04$, $p = .020$, $\eta = .25$. However in this case, a post-hoc Bonferroni test indicated that accuracy in the low
spatial cueing condition \((M = 0.84; SD = 0.04)\) was significantly higher than in the moderate spatial cueing condition \((M = 0.67; SD = 0.04)\), \(p = 0.016\). High spatial cueing \((M = 0.77; SD = 0.04)\) failed to differ significantly from spatial cueing that was either moderate or low (Figure 13).

In order to determine if accuracy varied differently for each condition between the first and the second session, a one-way ANCOVA of spatial cueing was conducted on accuracy improvement, with reading skills and spatial orientation skills as covariates.

The analysis yielded significant variations among spatial cueing, \(F(2,122) = 6.35, p = 0.002, \eta = 0.31\). A post-hoc Bonferroni test indicated that accuracy
improvement in the low spatial cueing condition ($M = .52; SD = .04$) was significantly higher than in the moderate spatial cueing condition ($M = .31; SD = .04$), $p = .002$. High spatial cueing ($M = .41; SD = .04$) failed to differ significantly from spatial cueing that was either high or low (Figure 14).

**Effects of conditions on navigation path**

In order to assess the effects of spatial cueing on navigation path (hierarchical and network navigation), a 3 Spatial Cueing (High vs. Moderate vs. Low) × 2 Navigation Path (Network Navigation vs. Hierarchical Navigation) fixed analysis of variance (ANCOVA) was conducted for the first session, with reading skills and spatial orientation
skills as covariates. A significant main effect of navigation path was found, 
\[ F(1, 126) = 5.70, p = .018, \eta = .21, \] showing that participants used hierarchical navigation 
\((M = 73.85; SD = 2.52)\) more than network navigation \((M = 53.73; SD = 3.21)\). A 
significant main effect of spatial cueing was also found, \(F(2, 126) = 15.53, p < .001,\) 
\(\eta = .44.\) A post-hoc Bonferroni test indicated that participants in the low spatial cueing 
condition \((M = 51.72; SD = 2.81)\) navigated less than participants in both the high spatial 
cueing condition \((M = 73.16; SD = 2.72), p < .001\) and moderate spatial cueing condition 
\((M = 66.49; SD = 2.85), p = .001.\) High spatial cueing failed to differ significantly from 
moderate spatial cueing.

*Figure 14. Improvement in Accuracy Between Sessions*
An interaction was found between spatial cueing and navigation path, $F(2, 126) = 10.73, p < .001, \eta = .38$ (figure 15). In the low spatial cueing condition, a post-hoc Bonferroni test showed that the difference between hierarchical and network navigation was significant ($M = 53.12; SD = 7.43), p < .001$, indicating that hierarchical navigation was superior to network navigation in this condition. A difference between hierarchical and network navigation failed to be found significant in both the high and moderate spatial cueing conditions. Additionally, a complementary one-way ANCOVA of spatial cueing on hierarchical navigation was conducted for the first session, but no

![Figure 15. Navigation Paths in First Session](image-url)
significant effect was found. On the contrary, a complementary one-way ANCOVA of spatial cueing on network navigation was conducted for the first session, and yielded significant results, $F(2, 126) = 19.41$, $p < .001$, $\eta = .49$. A post-hoc Bonferroni test indicated that participants in the low spatial cueing condition ($M = 26.00; SD = 5.64$) used less network navigation than participants in both the high spatial cueing condition ($M = 73.13; SD = 5.44$), $p < .001$ and moderate spatial cueing condition ($M = 62.08; SD = 5.72$), $p < .001$. High spatial cueing failed to differ significantly from moderate spatial cueing.

Subsequently, a similar 3 Spatial Cueing $\times$ 2 Navigation Path ANCOVA was conducted for the second session, with reading skills and spatial orientation skills as covariates. A significant main effect of navigation path was found, $F(1, 126) = 4.16$, $p = .043$, $\eta = .18$, showing that participants used hierarchical navigation ($M = 37.84; SD = 1.12$) more than network navigation ($M = 28.05; SD = 1.62$). A significant main effect of spatial cueing was also found, $F(2, 126) = 22.23$, $p < .001$, $\eta = .51$. A post-hoc Bonferroni test indicated that participants in the low spatial cueing condition ($M = 25.56; SD = 1.37$) navigated less than participants in both the high spatial cueing condition ($M = 37.39; SD = 1.33$), $p < .001$ and moderate spatial cueing condition ($M = 35.89; SD = 1.39$), $p < .001$. High spatial cueing failed to differ significantly from moderate spatial cueing.

An interaction was found between spatial cueing and navigation path, $F(2, 126) = 29.08$, $p < .001$, $\eta = .56$ (Figure 16). In the high spatial cueing condition, a post-hoc Bonferroni test showed that the difference between hierarchical and network
navigation was significant ($M = -8.04; SD = 3.55$), $p = .028$, indicating that network navigation was superior to hierarchical navigation in this condition. Similarly, in the low spatial cueing condition, a post-hoc Bonferroni test showed that the difference between hierarchical and network navigation was significant ($M = 34.02; SD = 2.93$), $p < .001$, indicating that hierarchical navigation was superior to network navigation in this condition. A difference between network and hierarchical navigation failed to be found significant in the moderate spatial cueing condition. Additionally, a complementary one-way ANCOVA of spatial cueing on hierarchical navigation was conducted for the

*Figure 16. Navigation Paths in Second Session*
second session, and yielded significant results, $F(2, 126) = 5.63, p = .005, \eta = .29$. A post-hoc Bonferroni test indicated that participants in the high spatial cueing condition ($M = 33.24; SD = 1.90$) used more hierarchical navigation than participants in the low spatial cueing condition ($M = 42.44; SD = 1.97$), $p = .003$. Moderate spatial cueing failed to differ significantly from spatial cueing that was either high or low. Also, a complementary one-way ANCOVA of spatial cueing on network navigation was conducted for the second session, and yielded significant results, $F(2, 126) = 37.14, p < .001, \eta = .61$. A post-hoc Bonferroni test indicated that participants in the low spatial cueing condition ($M = 8.67; SD = 2.85$) used less network navigation than participants in both the high spatial cueing condition ($M = 41.53; SD = 2.75$), $p < .001$ and moderate spatial cueing condition ($M = 33.95; SD = 2.89$), $p < .001$. High spatial cueing failed to differ significantly from moderate spatial cueing.

Finally, a 3 Spatial Cueing $\times$ 2 Navigation Path Improvement (Improvement in Hierarchical Navigation vs. Improvement in Network Navigation) ANCOVA was conducted, with reading skills and spatial orientation skills as covariates. Navigation path improvement failed to show a main effect. A significant main effect of spatial cueing was found, $F(2, 126) = 3.97, p = .021, \eta = .24$. A post-hoc Bonferroni test indicated that participants in the moderate spatial cueing condition ($M = 9.29; SD = 1.16$) showed an increased navigation more than participants in the low spatial cueing condition ($M = 4.87; SD = 1.14$), $p = .023$. High spatial cueing failed to differ significantly from spatial cueing that was either moderate or low.
An interaction was found between spatial cueing and navigation path improvement, $H(2, 126) = 10.74, p < .001, \eta = .38$ (Figure 17). In the high spatial cueing condition, a post-hoc Bonferroni test showed that the difference between hierarchical and network navigation improvement was significant ($M = -8.23; SD = 3.21$), $p = .014$, indicating that network navigation improved more than hierarchical navigation in this condition. Similarly, in the low spatial cueing condition, a post-hoc Bonferroni test showed that the difference between hierarchical and network navigation improvement was significant ($M = 12.78; SD = 2.36$), $p < .001$, indicating that hierarchical navigation

Figure 17. Variations in Navigation Paths Between Sessions.
improved more than network navigation in this condition. A difference between network and hierarchical navigation failed to be found significant in the moderate spatial cueing condition. Additionally, a complementary one-way ANCOVA of spatial cueing on hierarchical navigation improvement was conducted, and yielded significant results, $F(2, 126) = 6.38, p = .002, \eta = .30$. A post-hoc Bonferroni test indicated that for participants in the high spatial cueing condition ($M = 3.96; SD = 1.52$) hierarchical navigation improved less than for participants in both the moderate spatial cueing condition ($M = 9.47; SD = 1.59$), $p = .041$, and the low spatial cueing condition ($M = 11.46; SD = 1.57$), $p = .002$. Moderate spatial cueing failed to differ significantly from low spatial cueing. Also, a complementary one-way ANCOVA of spatial cueing on network navigation improvement was conducted, and yielded significant results, $F(2, 126) = 9.54, p < .001, \eta = .36$. A post-hoc Bonferroni test indicated that for participants in the low spatial cueing condition ($M = -1.73; SD = 2.40$) network navigation improved less than for participants in both the high spatial cueing condition ($M = 12.28; SD = 2.31$), $p < .001$ and moderate spatial cueing condition ($M = 9.11; SD = 2.43$), $p = .006$. High spatial cueing failed to differ significantly from moderate spatial cueing.
CHAPTER V

DISCUSSION

As a reminder, in this investigation, we asked participants to accomplish a searching task in a website. The website was presented to each participant in either one of three versions, which differed in the modality of their navigation. The modalities featured spatial cues at different levels: low, moderate, and high. The spatial cues were (a) spatial consistency, present in the moderate and high spatial cueing conditions, and (b) visual movement, present only in the high spatial cueing condition.

Spatial consistency was achieved by having the contents of the website move and scale as a whole within a single page, instead of opening multiple pages like in hyperlinking. Navigation with spatial consistency was similar to moving a camera or first-person point of view to different elements of the page. Although this metaphorical description of camera view was arguably relevant, it was not suggested to participants.

Visual movement was achieved by using an animation accompanying each navigation event in a website featuring spatial consistency. Navigation to and from the different elements of the page lasted a few moments, showing the elements of the page scale and move in real time. The navigation modality using visual movement in addition to spatial consistency was designed to provide the highest amount of spatial cueing.

The navigation behavior of participants was recorded, as well as their success at the book location tasks. In addition, we measured participants’s reading skills, spatial
orientation skills, and visual memory skills. Finally, we measured participants’s experience after navigating the website presented to them, in terms of how easy participants found navigation, and how participants enjoyed to navigate in the website.

Our results indicate that spatial cues have different effects on navigation behavior. Spatial cues affected both participants’s first navigation in the website and participants’s navigation improvement between the two sessions.

Novice Users

In the first session, participants in the high spatial cueing condition were found to be more efficient than participants in both other conditions. In other words, participants in the high spatial cueing condition correctly located more books in the same amount of time than participants in the other conditions. Particularly, the significant difference in efficiency found between high spatial cueing condition and moderate spatial cueing condition is to be highlighted. The navigation modalities of these two conditions differed only in the presence (high spatial cueing) or absence (moderate spatial cueing) of a 600ms animation at each navigation even, which led to the visual perception of movement. If animation was superfluous, it could have slowed down navigation because the duration of the animation would have taken away more time from navigation compared to the other conditions. Also, if animation had created disorientation rather than reducing it, navigation with animation would have led to lower efficiency. On the contrary, animation led to a higher efficiency. It could be argued that animation improved efficiency by providing perceptual cues to the element of focus on the page and guiding attention throughout navigation (Amadieu, Mariné & Laimay, 2011). However, because
the whole web page and each of its element were animated altogether during each navigation event, we believe that the animation did not specifically guide attention to certain elements. For this reason, we refute the hypothesis of attentional cueing to explain our results.

We conclude that the effects of animation on efficiency are best explained by internal mental simulations of movement as described by grounded cognition theories (Barsalou, 2008). As described in our hypotheses, we understand that ego-centered mental simulations of bodily movement took place in the conditions providing spatial cues, especially in the high spatial cueing condition which featured animated movement. The simulations enhanced by animation allowed users to predict what each navigation event would bring to them before clicking, reducing disorientation and improving performance.

Also, in the first session, participants were found to show a tendency to be more accurate in the high spatial cueing condition and the moderate spatial cueing condition than in the low spatial cueing condition. In other words, participants in the high and moderate spatial cueing conditions tended to make fewer errors when selecting books in relation to the total number of books they selected than did participants in the low spatial cueing condition. As shown by the results of efficiency, participants in the low spatial cueing condition did not locate more books than participants in the two other conditions. Thus, the trend in lower accuracy cannot be explained by a faster search behavior leading to a superficial processing of the book contents. Additionally, the activity of verifying if a book was a task target was designed to be extremely similar
across all conditions. Thus, we can infer that if participants in the low spatial cueing condition showed a lower accuracy, it could be because (a) they were unable to compare the contents of the book excerpt to the book description, which points directly to cognitive overload, or (b) they were unable to reach the correct book, and consequently selected another book for lack of a better option, which suggests disorientation in navigation. In conclusion, the results on efficiency and accuracy are consistent with each other, indicating that spatial cues can help reducing disorientation and lower the load on working memory, allowing for better performances on a simultaneous task.

Finally, navigation paths showed differences across conditions in the first session. Across the three conditions, participants used hierarchical navigation in similar amounts. Also, participants in the moderate and high spatial cueing conditions used network navigation as much as hierarchical navigation. However, participants in the low spatial cueing condition used network navigation less than they used hierarchical navigation. Consequently, the results show that participants in the low spatial condition used network navigation less than did participants in the moderate and high spatial cueing conditions. This indicates that the addition of spatial cues modified the way participants navigated in the information system. The differences in navigation are not only quantitative (efficiency, accuracy) but qualitative: a different type of navigation path appeared. Also, according to our results suggesting that spatial cues lower cognitive overload and disorientation, we advance that network navigation in the low spatial cueing condition caused more disorientation than the use of hierarchical navigation, making network navigation unsuitable in this condition. The impossibility to use network
navigation in the low spatial cueing condition can be a cause of the lower scores in efficiency and accuracy found in this condition.

All the results found in the first session indicate that novice users of an information system can benefit from the addition of spatial cues to a navigation modality. We found only positive results from the addition of spatial cues, although it could have been feared that animation would induce confusion and disorientation, and that a novel navigation modality would be harder to use than traditional hyperlinking. Spatial cues provided an increase in efficiency, accuracy, and ability to use network navigation. We believe that these findings strongly support the idea that movement simulations are a basic mechanism of navigation in information systems. Finally, the finding that simulations of movement operated by the computer in navigation can support mental simulations is very valuable to the field of web design.

Learning Effects

The efficiency of participants in the low spatial cueing condition improved more than the efficiency of participants in the high spatial cueing condition between the two sessions. This result indicates that a stronger learning effect has occurred between the first and the second session for participants in the low spatial cueing condition than for participants in the high spatial cueing condition. This suggests that the use of a navigation modality with low spatial cueing requires learning and practice to attain complete efficiency. Consistently with this idea, we found that efficiency did not differ across conditions in the second session, indicating that the differences found in the first session faded through the learning process.
Similar results were found on accuracy improvement between the two sessions. The highest improvement in accuracy was found for the low spatial cueing condition. However, this led participant in the low spatial cueing condition to be more accurate than participants in the moderate spatial cueing condition. One explanation could be the navigation path used by participants in the different conditions.

Results on improvement of navigation path indicate that participants in the moderate spatial cueing condition did not change the type of navigation path they used between the first and the second session. Conversely, participants in the high spatial cueing condition increased the use of network navigation against the use of hierarchical navigation between the two sessions, and participants in the low spatial cueing condition increased the use of hierarchical navigation against the use of network navigation between the two sessions. This suggests that in the low and high spatial cueing conditions, participants were able to adapt their navigation behavior to the navigation modality. Consequently, we argue that more spatial cues allow users to increase their use of network navigation against hierarchical navigation. In the moderate spatial cueing condition, participants might have been unable to select the most adapted type of navigation path, which could have led to a lower accuracy in the searching task.

Our results on improvement in navigation indicate that the strong positive effects found for novice users partially faded while participants became more experienced with navigation. Because participants could already use hyperlink navigation, the improvement found in the low spatial cueing condition suggests that this condition induced learning of the website materials. However, participants in the low spatial
cueing condition did not become more efficient or accurate than participants in the high spatial cueing condition. The effects of a longer exposure to low vs. high spatial cues could be explored in further research.

**Other results**

As expected, reading skills and spatial orientation skills had a positive effect on navigation. Higher reading skills or spatial orientation skills improved navigation in terms of efficiency or accuracy, as well as network navigation. This support the common idea that navigation required both semantic and spatial skills (Conklin, 1987; Dourish & Chalmers, 1994), although as indicated in our hypotheses, the effects of reading skills could be due to the nature of the materials —books and text excerpts. More interestingly, visual memory skills failed to have an effect on any measured navigation behavior. This could possibly be due to a flawed measure of visual memory skills, caused for example by participants's fatigue after a series of spatial tasks (the measure of visual memory skills was taken at the end of the experimental procedure). However, this could also indicate that participants's navigation did not centrally rely on a mental map, thus rendering visual memory skills irrelevant to the success of navigation. We raise the question that mental maps could have been found of central importance in previous research (Boechler, 2001; McDonald & Stevenson, 1998; Nilsson & Mayer, 2002; Stanton et al., 1992) because mental maps were emphasized by the materials employed.

Within the framework of grounded cognition, emphasizing mental maps could have led to extrinsic or allocentric mental simulations of the information system. On the contrary, our materials emphasized intrinsic or ego-centered mental simulations, which could lead
participants not to rely on mental maps. This would be consistent with our results indicating that spatial rotations skills had an effect on navigation behavior while visual memory skills did not.

Finally, our results indicate that participants who correctly located more books rated the website as easier to use, and participants who rated the website as easier to use also reported liking the website more. This suggests that processing fluency (see Alter & Oppenheimer, 2009), due to participants skills or due to the spatial cues provided, led participants to enjoy navigation to a higher degree. Thus, increasing participants' efficiency by providing spatial cues contributed to provide a better experience to participants. This finding could be applied to the field of web design.

Limitations

A first limitation of this study is due to the reading skills data collection. The data collection was operated through the use of a computer program which, by a flaw in its design, did not provide a result for each item of the measure. The computer simply outputted a numeric total score for each participant. For this reason, it was impossible to take a measure of the test's internal consistency using for example a Cronbach's alpha. As a result, we don't know the actual internal consistency of this measure on our sample of participants.

Also, the two sessions of search activity in the website were not of the same duration. The first session lasted ten minutes, but the second session lasted only four minutes. This difference did not provide any advantage in the study, and prevented us from directly comparing the two sessions to each other. Intermediate scores of expected
performance in the second session had to be calculated from the scores obtained in the first session, in order to subsequently create scores of improvement on each navigation behavior. This diminished the accuracy of our data on improvement between the two sessions. Additionally, the duration of four minutes of the second session did not provide as much accuracy as it would have if it had been maintained at ten minutes of duration.

Moreover, the targets of the search task were books that differed in many aspects. The covers, the excerpts, the titles, and also the themes of the books were different. For this reason, it is highly possible that some books were easier to find than some other books. Additionally, the descriptions of the books provided to participants also varied and added to the possibility of a book to be easier to find than another book. Moreover, the book targets of the second session differed from the book targets of the first session. For this reason, the comparison between the first and the second session is only valid under the assumption that task difficulty was similar between the two sessions. Nonetheless, the comparison of navigation behaviors and improvement in behaviors between the two session is valid between participants, because all book targets were identical and were to be located in the same order for all participants. All participants across the three conditions would be evenly affected by variations in difficulty to locate books.

Finally, our investigation lacks measures of disorientation, working memory load, metacognition, mental map of the information structure, mental simulations of navigation, and long-term memory of the website. Thus, the behavioral results observed can only allow inferences supported by the theoretical background provided by the
As a consequence, the theoretical deductions explaining our results suffer from being unfalsifiable, because drawn from theories rather than the absent measures listed above. Future investigations featuring these measures are required to ensure the falsifiability of the conclusions.

Implications for Future Research

As mentioned in the limitations of the study, cognitive measures going beyond the scope of the behaviors observed in this study have to be taken in further research to confirm or infirm and complement our results. Nevertheless, this study provides a new perspective on information system and website navigation. The application of the point of view of grounded cognition on website navigation allowed us to improve navigation in various aspects, thanks to technological advance. As Conklin (1987) suggests, technology can improve navigation to connect human minds to information systems. In this line, future research in navigation should explore the possibilities of supporting mental simulations by additional means. Also, research in cognition could complete our findings on information system navigation with research on navigation in virtual spaces.

Implication for Web Design

Various technologies exist to create zooming effects, sliding banners, or animated movement in websites. From the point of view of the user experience, the most creative and impressive features that can be added to a website might however be a detrimental addition. Our study shows that certain modern spatial features can have positive effects when used adequately, and our conclusions provide a basic understanding
on how and when to use the spatial features. Our results inform us that spatial features can be a successful addition to a website if (a) they are integrated within the contents of the website and not added as a separate element, (b) they provide consistent spatial properties to the contents of the website, and (c) they stimulate ego-centered mental simulations by mimicking first-person movements.
REFERENCES


