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Spatial Cognition research:
The human navigation process and its comparability in complex real and virtual environments

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SUMMARY

Virtual environments are already used frequently in research and practice. However, it remained unclear to what extent human spatial behavior in real and virtual environments are comparable and how well spatial knowledge acquired in virtual reality can be transferred to reality, and vice versa. The first experiment directly compares navigation behavior in a real and virtual version of the same environment and investigates the effects of training and navigation environment on navigation process and performance.

It results that transfer of spatial knowledge between reality and virtual reality is possible in principle, but with different levels of performance. Analysis of navigation strategies shows that the virtual environment does not reduce the number of possible strategies and that subjects use the same strategies than in reality. Thus, virtual realities are comparable to reality concerning the navigation process, but not with regard to performance.

Strategies give an insight into the existence and the structure and details of cognitive maps. Another question is what kind of spatial knowledge do people acquire when moving in an unfamiliar environment? Landmarks tend to be remembered easily, but results of both experiments prove that route and survey knowledge as well can be developed from the very first contact with an environment. The various definitions, characteristics and types of landmarks are explained in the theory section and later confirmed by the results.

The second experiment investigates the effects of route familiarity on composition of ordinary route descriptions and the effects of different versions of route descriptions on navigation performance. Furthermore, I researched if subjects are able to give good route descriptions and direction estimations in a hardly known area and if self-evaluations of orientation and navigation abilities correspond to objective measures of performance. When describing unfamiliar routes, subjects use more landmark related information. Likewise, route descriptions based on landmark information lead to higher navigation performance on one route (but not on the second route).

Only a few subjects manage to describe all crucial sequences, i.e. ordinary route descriptions do not constitute a good navigation aid. Furthermore, good navigators are not necessarily good route descriptors.

Direction estimation performance indicates that half of subjects have developed survey knowledge of the campus which further confirms the early development of cognitive maps in unfamiliar environments.
Subjective evaluations and objective performances do not match. Men and women differ rather on the confidence level than on the performance level. Sociodemographic factors like education, gender and age have less impact on spatial cognition than navigation practice and field dependency.

DEUTSCHE ZUSAMMENFASSUNG

Virtuelle Realitäten werden in Forschung und Praxis bereits häufig eingesetzt. Allerdings wurde bisher kaum untersucht, inwieweit menschliches, räumliches Verhalten in reellen und virtuellen Umgebungen vergleichbar ist und wie gut räumliches Wissen, das in einer virtuellen Umgebung erworben wurde, in der entsprechenden reellen Umgebung verwendet werden kann und umgekehrt.
Das erste Experiment vergleicht Navigationsverhalten in einer reellen und einer virtuellen Version des selben Gebiets und untersucht die Auswirkungen der Trainings- und Navigationsumgebung auf den Navigationsprozess und die Leistung.
Die Ergebnisse belegen, dass der Transfer von Raumwissen zwischen reeller und virtuelller Umgebung prinzipiell möglich ist, allerdings mit unterschiedlichem Leistungsniveau. Die Analyse der verwendeten Navigationsstrategien zeigt, dass die virtuelle Realität die Zahl der verwendeten Strategien nicht reduziert und dass die Probanden in beiden Umgebungen die selben Strategien verwenden. Virtuelle und reelle Umgebungen sind also vergleichbar bezüglich des Navigationsprozesses, nicht jedoch mit Bezug auf die Leistung.
Navigationsstrategien geben Hinweise auf die Existenz und das Aussehen von kognitiven Karten. Damit verbunden ist die Frage, welche Art von Raumwissen Menschen bei der Navigation in unbekanntem Terrain erwerben. Landmarken werden üblicherweise leicht erinnert, aber die Ergebnisse belegen, dass auch Routenwissen und Überblickswissen ab dem ersten Kontakt mit einem Gebiet entwickelt werden können. Im Theorieteil werden verschiedene Definitionen des Begriffs „Landmarke“ gegenübergestellt und unterschiedliche Typen von Landmarken beschrieben.

In einem weiteren, komplexen Feldexperiment wird mit verschiedenen Aufgaben untersucht, wie Menschen Wegbeschreibungen anfertigen, ob die Wegbeschreibung z.B. von dem Vertrautheitsgrad der Umgebung und den Umgebungsmerkmalen abhängt, was eine gute Wegbeschreibung ausmacht und welche Navigationsstrategien verwendet werden. Weiterhin wird überprüft, ob die Probanden gute Richtungsschätzungen in einem kaum bekannten Gebiet vornehmen können und inwieweit die Selbsteinschätzung von räumlichen Fähigkeiten mit der objektiven Leistung übereinstimmt.

Beim Beschreiben wenig bekannter Routen verwenden die Probanden vor allem Landmarkeninformationen. Ausserdem navigieren sie mit einer Wegbeschreibung, die nur auf Landmarken basiert besser als mit einer rein routenbasierten Wegbeschreibung der selben Route, allerdings nur auf einer der beiden Experimentalrouten.

Nur wenige Probanden beschreiben alle wichtigen Sequenzen der Route, d.h. die meisten dieser Wegbeschreibungen stellen keine gute Navigationshilfe dar. Ausserdem stellte sich heraus, dass gute Navigierer sind nicht notwendigerweise auch gute Wegbeschreiber sind.

Die Leistungen bei den Richtungsschätzungen zeigen, dass die Hälfte der Probanden bereits Überblickswissen entwickelt haben. Auch dieses Ergebnis bestätigt meine These, dass die Entwicklung kognitiver Karten bereits beim ersten Kontakt mit einer neuen Umgebung beginnen kann.

Subjektive Einschätzungen der eigenen räumlichen Fähigkeiten und objektive Leistungen im Experiment stimmen nicht überein. Geschlechtsunterschiede gibt es hauptsächlich bei der Selbsteinschätzung, dagegen kaum auf der Leistungsebene. Insgesamt haben soziodemographische Faktoren, wie Bildung, Geschlecht und Alter geringere Effekte auf die Navigationsleistung als die Intensität bisheriger Navigationserfahrungen und Feldabhängigkeit.

PREFACE

This dissertation was composed during my two year assignment (March 2002 to March 2004) at the Human Factors Institute in the Faculty for Aerospace Technologies of the University of the Armed Forces Munich. The German Research Foundation supported my collaboration in this project within the focus program spatial cognition.

I want to thank everybody who contributed to this doctoral thesis.

First of all, I want to thank PD Dr. Michael Popp who inspired me to work in the field of spatial cognition, a topic which was completely new to me when I started to work on it in March 2002. With the establishment of the Vision Dome, he has invested many years of preliminary work and created experimental facilities that are unique in Europe. This was surely a decisive reason for his admission to the focus program spatial cognition of the German Research Foundation which finally enabled me to work on this project. The excellent performance of the Vision Dome was also a main prerequisite for the quick realization of the experiments and the following composition of this thesis. PD Dr. Michael Popp took over the initial training and the further supervision of my work at the Human Factors Institute. He was always open to give me competent advice and to discuss projects and results. He also took over the proofreading of this dissertation. I want to thank him very much for his remarkable support and inspiration as well as for his pleasant collaboration.

Furthermore, I want to award particular words of gratitude to Prof. Dr. Berthold Färber and to my colleagues at the Human Factors Institute, who contributed enormously to a pleasant work ambiance.

In addition to that, I want to say thank you to all the students of Aerospace Technologies who worked on my project while writing on their seminar paper or masters thesis. The following students contributed considerably to the success of my experiments: Jürgen Böhnlein, Stefan Conrad, Alexander Gehres, André Gieseler, Michael Ruser, Thorsten Slany, Alexander Uebel, and Lars Wilhelmy.

Finally, I would like to thank the 'Friedrich-Ebert-Foundation' who supported my university studies for five years (1996-2001) at home and abroad and thereby contributed to the acquisition of the prerequisite degree for this doctorate.

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1. Theoretical and empirical framework

1.1 Introduction

Orientation and navigation are important aspects of human actions. We need to know where we are and how to reach our destination in order to comply with our tasks in all contexts. Therefore, orientation in time and space and the use of successful navigation strategies are essential abilities.

When taking the same routes over and over again, e.g. from home to work or to school, to the next supermarket, etc., people navigate, although they often do not think consciously about navigation. At the latest, when people have to explain a route to somebody else or when navigating in an unfamiliar or less familiar terrain, people start thinking about what they know about the terrain in question and how they could manage to reach their destination.

People have a basic desire to know where they are. Spatial disorientation affects people's well being. Therefore, if people are unfamiliar to the area, they often take along or search for orientational aids, like a map, verbal descriptions or even a navigation system. Travelling in an unkown area or country, navigation may require a great temporal and organizational effort. To avoid this, many people book guided all expense tours when they go on vacation. In addition to travelling, navigation is relevant at a large number of further fields, e.g. route planning, aviation, sailing, driving, rock climbing, alpine tours, hiking, bike tours, etc.

What do the terms orientation and navigation actually mean?

Orientation means knowing about one's actual position and the spatial relations between various locations. As the other locations can be located outside of our actual perceptional range, orientation is a predominantly cognitive process.

Orientation is the first step of the navigational process, which continues with choice of the route, keeping the right way, and finally discovery of the goal.

Navigation means solving a spatial problem, usually to get from one location to one or more other locations. Contrary to pure orientation, navigating people move and they have got one or more specific goals. So, we can orientate without navigating, but we cannot navigate without orientating.

If we fail to establish a connection between the actually perceived real world and the presention of the terrain in our mind (cognitive map), we may get lost (Downs & Stea, 1982, p.80, 86).

Losing one's way mostly causes a large number of problems to the unsuccessful navigator. In any case, it means not reaching the goal or at least arriving late or too late to do what one planned to do. In addition, the wrong track may take the pedestrian / driver to a dangerous suburb, e.g. in New York, or the mountaineer to a tricky rock wall that is dangerous or even impossible to overcome. Hence, successful orientation and navigation are important actions of everybody's everyday life.

Spatial cognition research enhances our understanding of human orientation and navigation in space. For example, it is investigated how people manage to orient themselves in complex spatial systems like a city. Knowing about the navigation process is important for many reasons, e.g. in order to provide and improve navigational aids and training opportunities, and to structure an area by adequately placing landmarks and streets (town planning).

In this thesis, I focus on ordinary human spatial behavior without any navigational aids in an unknown urban area .

1.2 The environmental perception and orientation process

In this chapter, I will shortly explain navigation related processes based on an example describing an ordinary navigation situation.

Imagine that a woman called Sue is visiting her friend Bob for the first time in Portland. Therefore, he fetches her up at the railway station and both walk to the friends house, with is located at about 1500 meters from the station.

On this route, there is an enormous number of cues that Sue could perceive.

In addition to visual cues, the other senses, like locomotion, tactile sense, olfactory sense, and sense of hearing enable her to perceive further pieces of information.

However, she perceives only a very limited selection of cues, because human perception is selective. First of all, capacity of short-term memory is limited. Furthermore, existing knowledge, actual needs, personal schemata and expectations influence actual spatial perception. So, Sue is likely to already have an imagination of

Portland and the area where Bob lives before actually getting there. This previous imagination may result e.g. from studying a book or map about Portland, from Bob's descriptions or from her general knowledge about the structure and appearance of big cities.
These schemata and expectations enable her to quickly orientate in this unknown city. However, prior expectations may also complicate the learning process if they superimpose actual experiences, but turn out to be misdirecting for the environment in question.

Now in short, what happens to the selected cues that are actually perceived?
In order to enhance its understanding, **human perception** can be subdivided into the following three stages. First, the sensations are coded, i.e. physical energy is transformed into neuronal activity of the brain cells. Then, the pieces of information are summarized and organized. Finally, the features of the perceived objects are classified into familiar categories and schemata (Zimbardo, 1995, p.159-163). Schemata act as frameworks. These familiar categories and existing schemata are part of the previously existing knowledge (top-down process) that influences the classification and the whole bottom-up perception process.
Classifying means organizing and reducing the amount of information and thereby facilitating it. Although this reduction may have disadvantages (e.g. in case of wrong classifications), it facilitates memory storage and retrieval.
The pieces of information may be organized and classified according to various principles. Thus, the same information may be stored with relation to various points of view. For example, a certain location on the route may be remembered as junction of broad streets (which may not be specific enough for recognition if there are various on the route), junction of 20th and Clay street, place with the large red painted building (landmark), place where Bob met a friend (action) or went into the bakery (action+landmark), etc. So, Sue does not just store the pure coordinates of the location, but related pieces of information, e.g. actions, intentions, and functions are stored nearby.
To sum up, the human perception and memorizing process is interactive, i.e. actual spatial perceptions (bottom-up processes) interact with existing knowledge, schemata and expectations (top-down processes). The perception of our

surroundings is based on these general interactive perception and analysis processes, orientation and navigation require our entire sensual capacity.
Now, let's get back to Sue. One week later, she returns to Portland. She is now located in front of the central railway station and wants to get to her friend's house by herself. First of all, she has to orient herself to know where she is and she needs to think about where exactly she wants to go to (part of town, street name and number, eventually the next bus or tram station) and how she will get there.
This time, she is supposed to find her way alone. She tries to remember what she knows about Portland and especially about the trained route, i.e. the relevant pieces of spatial information. These pieces of information may be organized according to various principles other than their appearance on the route, e.g. personal importance, the object's conspicuousness and contrast with the environment, associations, etc. Therefore, she has to organize these pieces of information in a meaningful order, which means to arrange them according to the sequence of importance on the route. Remembering an area and route means reconstructing it in one's mind (Neisser, 1974, p.358). Gaps, e.g. gaps of the route, are often filled with elements that are part of one's general schemata and therefore expected, although they may not occur in the real environment .

Now, if she is able to develop an internal representation of the connection between actual position and goal, i.e. the route, she can decide if she will walk there or take a means of transportation. If she has developed a good cognitive map of the area, she may even decide on various possible routes, e.g. to take a nicer or shorter route, than she did last time with her friend who made a detour to the bakery. In both cases, she can choose a route and pay attention to keep the right way.
However, it is also possible that she remembers only parts of the route. If she knows at least the first part of the route, she may start walking on the remembered part hoping to recognize further familiar parts once she is on her way. It is easier to recognize an object and then associate actions than to independently remember it. Furthermore, she can still ask a passer-by for the way once she gets lost. Usually, it is easier to explain a shorter route than the long distance from the railway station to the friend's house. Of course, she can usually consult additional aids. She could have a look at a map before leaving the railway building, or phone her friend.

The above description distinguishes different kinds of spatial knowledge. She may have an internal representation of the route (route knowledge) or even of the whole area including the station and Bob's house (survey knowledge). Both route and survey knowledge enable her to reach her goal. However, if she remembered only landmarks (landmark knowledge) which is possible as well after only one training unit, she would not find Bob's house without additional help. Anyway, spatial knowledge is usually fragmented. Both its completeness and the number of included details increase with training.

1.3 The navigation process

Assuming that people have developed route or survey knowledge and thus can decide on the route, the navigation process consists of various stages that can be repeated several times. Downs & Stea (1982, p.171-186) divided the navigation process into four consecutive, interlinked steps:

1. Orientation

   Orientation to know where you are, the surrounding environment has to be matched with the cognitive map, thereby the own actual position is determined in relation to landmarks;

   To my mind, other elements of cognitive maps, like nodes, edges, and paths may help to determine one's present location, as well.
2. Choice of the route

   Cognitive connection between the present position and the goal; implementation of the action plan consisting of a series of purposeful single actions along the route;
3. Keeping the right way

   Monitoring the implementation of the route plan, for this purpose the cognitive map is compared constantly to the perceived environment
4. Discovery of the goal

   Comparison of cognitive map and environment in order to determine if the goal is reached

In order to orientate oneself, to choose the right track and to keep it, people use various navigation strategies. This is one of the main research topics of my thesis that is based on the fundamental question: how do people orientate and navigate without artificial or technical aids;

Navigation strategies are decision rules or principles that are the basis for intentional navigational actions. These strategies may, but do not necessarily have to include a action plan and possible cognitive steps in advance. Some strategies can be used during the whole navigation, e.g. knowing the direction from start to goal enables the navigator to find a route to the goal, if he/she succeeds in deducing the direction from his/her actual position to the goal at the relevant junctions which are representing new decision points. Other strategies, e.g. landmarks or route knowledge, require the remembrance of a sequence of information, i.e. a sequence of landmarks or turnings.

1.4 Landmarks

1.4.1 Definition

'Landmark' is one of those terms that are frequently used, both in everyday language and in science, often without even discussing or further agreeing on its definition. Scientific definitions vary with the academic discipline (e.g. architecture, geography, psychology, etc.), but also within one discipline. I will cite a few definitions from various fields, show possibilities to distinguish different kinds of landmarks, and finish with the operational definition used in this paper.

The landmark features proposed by the cited definitions and types of landmarks are summarized in Table 1. Therefore, definitions are assigned a letter (A-J) which will be used in Table 1 in order to identify the corresponding definition.

There is a broad margin for landmark definitions mostly featuring a common basis (objects that are easily visible, distiguishable from the environment, and useful for navigation). Definitions differ with regard to emphasis or additional aspects.

In order to give an idea of this range of definitions, I want to cite a broad interpretation given by Presson & Montello (1988) and, for comparison, a more narrow definition given by Werner, Krieg-Brückner, Mallot, Schweizer & Freksa (1997).

According to Presson & Montello (1988), landmarks are visually distinguishable objects that are perceived and remembered (*definition A*). In this definition, only two subjective features have to be fulfilled in order to qualify for landmark: remembrance and distinguishability. Therefore, this definition encompasses a very large number of objects that potentially qualify for landmark.

Werner, Krieg-Brückner, Mallot, Schweizer & Freksa (1997) define landmarks as „distinkte, stationäre und saliente Objekte oder Reize, die als Referenzpunkte dienen können“ (*definition B*). They agree that landmarks are distinguishable objects. In addition, the objects have to be stationary and be used as a point of reference in order to qualify for landmark. Thus, contrary to Presson & Montello (1988), the landmark definition according to Werner et al. (1997) does not include objects that are distinguishable and remembered, but that are movable or that are not used as a point of reference. So, the definition by Werner et al. (1997) is more narrow and contains a smaller number of objects.

The characteristic of landmarks to be a point of reference is emphasized by many other authors, e.g. Sadalla, Burroughs & Staplin (1980) who describe landmarks as basing points that are remembered better than others and that specify locations of other points (*definition C*). Just like Presson & Montello (1988), they state that landmarks are (better) remembered. By adding the adjective ‘better’, they probably imply the reasons for better remembrance, e.g. that landmarks are distinguishable and contrast with the environment, but do not name these aspects.

Another author citing the reference aspect is Lynch (1960) who also describes additional aspects. He regards landmarks as optical points of reference whose main character is the singleness within its surroundings; Moreover, Lynch (1960) describes further aspects increasing the probability to be recognized (*definition D*).

Objects contrasting significantly with environment and background are more easily recognized. This is an objective feature whereas the above noted aspect ‘distinguishable object’ is the result of subjective perception. Nevertheless, an objectively contrasting object is likely to be considered as distinguishable from its environment, as well. As all but one definitions I found describe either the contrasting or the distinguishable aspect, it is possible that many authors do not differentiate between both aspects and actually mean the same criterion. Lynch (1960) also notes an object's or a view's uniqueness which may mean that it is distinguishable easily from others.

Furthermore, a landmark's obvious and plain shape enhances its recognizability as well as the reinforcement of the visual cues by sounds or odors. Here, Lynch (1960) is the only author who explicitly notes the influence of non-visual senses. I think that this is a very important cue, because often the combination of cues perceived via different senses makes people remember an object, e.g. the Indian restaurant can be seen, smelt (spices), and eventually heard, especially if guests are sitting on the terrace. Often the visual cues are even preceded by other sensual cues, e.g. someone first smells spicy food, consequently looks around to see where the smell comes from, and then actually sees the restaurant.

Lynch (1960) notes two other aspects that are rarely mentioned by other authors. One aspect, the object's location at nodes where route decisions have to be made, relates to the object's environment, just like the contrasting and the distinguishing characteristics. These characteristics show that the property to be a landmark is no absolute characteristic, but depends on the surrounding environment. Besides, the probability that an object is remembered is increased by the existence of a legend about the object. Most people easily remember interesting stories and anecdotes and thereby remember the associated object. Likewise, the function and meaning of objects/buildings provide helpful associations, e.g. a rather inconspicuous building housing the city hall may be a landmark, because the inhabitants of the city do not just see a grey building, but recognize the city hall.

Even movable objects that move slowly and regularly, like the sun, can be global landmarks. So, in contrast with other authors (Bill, 2001; Werner et al., 1997), Lynch (1960) does not restrain landmarks to stationary objects. Furthermore, he analyzes the visibility of landmarks and differentiates local and global landmarks.

The following definition originates from another discipline, geomatics, but actually, it is very close to the definition given by Werner et al. (1997).

Encyclopedia of geomatics (Bill, 2001):

> „Eine Landmarke ist ein ausgezeichnetes, räumlich verortetes Objekt, das sich deutlich von der Vielzahl von Umweltinformationen, die der Mensch wahrnimmt, abhebt.“(*definition E*)

Contrary to Lynch (1960), but agreeing with Werner et al. (1997), Bill (2001) defines landmarks as stationary objects. Bill is the only author who notes both the subjective feature ‘distinguishable object’ and the objective feature ‘contrast with the environment’.

Beyond science, the term of landmark is used and defined in various practical disciplines, e.g. in town planning, aviation, coastal traffic, and mountaineering. Actually, men have been using landmarks a long time before landmarks became a research topic and were analysed scientifically. Some researchers take over the term as it is used according to common sense, whereas others create their own definitions. That’s why there is a large variety of definitions now.

For example, landmarks are important in the sports of sailing. There, it is used for navigation purposes as well. To illustrate, I cite one definition from the sailors’ encyclopedia „Der Modellskipper 2000-2003“ (Kölbl):

> „Von See aus gut sichtbarer und unverwechselbarer Punkt an der Küste, der zur Schiffortbestimmung in der terrestrischen Navigation benutzt werden kann. Eine natürliche, markante Landmarke kann ein Einzelbaum, ein Schornstein, ein Sendeturm, Bake, Mühle, Windrad oder ähnliches sein.“(*definition F*)

This definition refers to global landmarks, because they have to be recognized easily from the lake/river/sea. The object has to be distinguishable from others in order to allow for unequivocal identification. Furthermore, the encyclopedia gives examples for naturally created landmarks, probably because most artificially created landmarks, like e.g. signboards, are rather local landmarks.

1.4.2 Types of landmarks

In addition to defining a landmark, we gain further insight into the nature of landmarks by describing different kinds – here depending on the landmark’s creation (Böhme, 2003), visibility (Steck & Mallot 1998), and location on the route (Herrmann & Schweizer, 1998).

Böhme (2003) gives a broad definition („A landmark is one or more perceptually distinctive features of interest on an object or locale of interest."), indicates possible uses (topological route planning and development of cognitive maps), and differentiates the creation of landmarks. He emphasizes the objective aspect landmark creation and distinguishes naturally (an already existing positioning of features is used for navigation) and artificially (additional features are added in order to improve perception and differentiation of objects and places) created landmarks. Furthermore, according to Böhme (2003), a landmark does not necessarily have to be a self-contained object. The positioning of conspicuous features may form a landmark as well (*definition G*).

As already mentioned at Lynch's (1960) definition, two kinds of landmarks, local and global landmarks, can be differentiated according to the landmark's visibility from a distance. Steck & Mallot (1998) define local landmarks and global landmarks as follows *(definition H)*:

- Local landmarks: visible only from short distances, often associated with route decisions, e.g. normally sized houses, signs, small, but striking objects
- Global landmarks: visible from far away, define an allocentric frame of reference and provide direction knowledge, e.g. sunset, stars, mountains, high towers or buildings

Nevertheless, a global landmark can be a local landmark as well once you are right next to it, i.e. the same object may take over both roles. In addition to the landmark's visibility, Steck & Mallot (1998) describe its adequate use for navigation. Local landmarks are an important part of route knowledge, as turnings at junctions are frequently associated when recognizing the local landmark. By contrast, global landmarks do not give explicit route information at a specific node, but rather provide general direction knowledge. The navigator has to derive the location of the searched route or goal and the adequate turning decisions from the view of the global landmark. Especially if the goal is still far away from the actual position of the navigator, global landmarks are useful to find the district/area where the goal is located.

Last but not least, as already mentioned by Lynch (1960), landmarks can be grouped according to their location on the route. Herrmann & Schweizer (1998) distinguish three classes of landmarks. First, there are landmarks that are localized outside the path or route, but easily visible, salient, and useful for orientation. Supposably, this are mainly global landmarks. By contrast, trailmarks are localized on the route. The third group encompasses ‘decision related trailmarks’ at nodes. Both kinds of trailmarks seem to be local landmarks differing with regard to their exact location on the route. Trailmarks are passed when moving on the route and may be used to confirm that one is on the correct route, whereas ‘decision related trailmarks’ are located at decision points (usually nodes) and help the navigator to make a decision on the continuation of his/her way by providing associated knowledge (e.g. turn left at the church).

Herrmann & Schweizer (1998) define landmarks as internal representations of locations that are particularly salient to a person. Saliency results from the object’s conspicuous characteristics (e.g. color, size) or from associations like personal memories or general knowledge. In other words according to Lynch (1960), good landmarks are distinguishable and feature a specific meaning or even a legend. Landmarks function as cognitive bases for the development of route knowledge (*definition I*).

Both Herrmann & Schweizer (1998) and Lynch (2001) emphasized the landmark’s location on the route. According research was done by Cohen & Schuepfer who investigated 1980 the effects of a landmark’s position on a route on the remembrance of its location in a laboratory experiment. They found that landmarks indicating a correct turning could be localized significantly better than those landmarks indicating a wrong turning or no turning.

These results were replicated 1998 by Jansen-Osmann in an actively explored virtual environment. In addition, her experiment confirms the importance of landmarks as way-finding aids. Subjects learnt the route with landmarks significantly faster than the route without. Thereby, as already shown by Cohen & Schuepfer (1980), the position of landmarks is vital. Landmarks associated with a right turning can indicate strategic nodes in terms of Lynch (1960, see also Chapter 2.3.5).

My own operational landmark definition *(defintion J)* is described in Chapter 1.4.4.

1.4.3 Summary and further analysis

Definitions cited above demonstrate that landmarks are attributed various characteristics. Thereby, most definitions do not contradict one another.

However, definitions differ with regard to emphasis or additional aspects. A few definitions (F, H, I) are specified according to its supposed users or field of use.

Most of the presented definitions describe three different criteria that have to be fulfilled or enhance an object's chances in order to qualify for landmark. Considering all cited definitions, it is possible to distinguish ten different features that can be grouped into objective and subjective features. Table 1 gives an overview of the features noticed in the cited definitions. Objective features are physically unequivocal attributes of an object and represent the emitter of cues, whereas subjective features represent the cue receptor perspective and are based on the (interindividually different) effects of cues on the individual's perception and interpretation process.

On the one hand, objective criteria are less equivocal. If an object does not fulfill the objective criterion of a certain definition, it cannot become a landmark, just because somebody uses it as a landmark. However, as described in Chapter 1.4.1, the identification of an object as a personal landmark does depend on somebody's cognitive concepts, interests, and expectations. Certainly, definitions likely refer to objects identified as landmarks by the majority of people. Thereby, it should be defined the majority of which population is considered. On the other hand, relating to subjective features, an object may potentially fulfill the criteria, but the question is how many or what percentage of persons has to perceive a feature so that it can be attributed to the object.

In the following, it is recapitulated what are these relevant features. There are five objective and five subjective landmark features.

Objective features

Within the objective features, there is one feature that has to be fulfilled (contrast), another one on which some definitions disagree if it is really necessary (stationary), and three features describing various landmark varieties (creation, visibility, location).

First, the object has to **contrast with the environment** which often results from visual attraction. According to Sorrows & Hirtle (1999), differences in size, colour or shape increase an object's visual attraction. This refers to the landmark's façade. Its size, colour and shape have to be considered in relation to the surrounding objects' characteristics. Objects contrasting highly with their surroundings are rather qualified for landmark, e.g. a green painted house standing in a street with white houses. Another important aspect is the object’s visibility. Both the amount of visible elements and its kind are relevant. The more of an object visible, the better it qualifies for landmark.

	Objective features					Subjective features				
Def.	Creation	Contrast	Visibility	Location	Stationary	Point of ref.	Use	Remembrance	Legend	Distinguish.
A								x		x
B					x	x	x			x
C						x	x	x		
D		x	x	x		x	x		x	
E		x			x					x
F	x		x				x			x
G	x						x			x
H			x				x			
I			x	x			x	x	x	X
J	x	x	x	x		x	x	x	x	x

Table 1: Landmark features proposed by various definitions

The contrast feature is cited only by two definitions (D, E) which probably results from the similar use of the subjective feature ‘**distinguishable**’ that is cited six times. Taking both features together there are only two definitions (C, H) that do not mention the contrasting or distinguishing aspect. This shows that the property to be a landmark is no absolute characteristic of the respective object. It rather depends on the surrounding environment. This means that the landmark does not need to be a conspicuous object itself, but it has to differ from its sourroundings. This difference that makes an object contrast with the environment and distinguishable, is necessary to attract attention. The difference may be created e.g. by form, color, or architectural style.

The only disagreement between definitions can be found with respect to the **stationary** aspect. According to Bill (2001) and Werner et al. (1997), only stationary objects can be landmarks. The main reason may be that non-stationary objects can be relocated easily. This problem can be bigger for subjects actively searching for such a vanished landmark than for those people using it once they recognize it at actual sight.

Nevertheless, non-stationary objects are likely to be used as landmarks under certain conditions. Movable landmarks can be useful landmarks if the time lag between two navigations is pretty short, if characteristics of movable objects indicate local invariance or if the location's function is the memorable feature.

In order to be used successfully for orientation, the object has to remain stationary during the relevant period of time or move regularly, e.g. like the sun, so that the navigator knows which direction is indicated by this global landmark. For example, I assume that most hikers, sailors, and mountaineers are able to consider the actual time and relate it to the position of the sun. They often use the actual position of the sun for orientation instead of using a compass. This means that the sun is a global landmark for a large number of people.

Another case are principally movable objects that can be expected to remain stationary during the time in question, e.g. a parked car with a flat tire and covered by lots of dust and leaves is unlikely to be removed often.

Finally, people often remember a location's function which usually remains more constant than the movable objects themselves. For example, in case of the motorcycles or the furniture standing outside on the campus of my university, people may rather remember that there is a parking spot for motorcycles or a place where tables and chairs are standing outside.

Actually, Lynch (1960) emphasizes that movable objects can qualify for landmark.

To my mind, both stationary and non-stationary objects can qualify for landmark, given that the above mentioned conditions are fulfilled.

In case of stationary objects, the **landmark's position on the route** (outside the route, on the route, or at decision points) is important for a landmark's use and significance. This was explained by definitions of Lynch (1960) and Herrmann & Schweizer (1998) and empirically proved by Cohen & Schuepfer (1980). Although the landmark's location is an important aspect, only two definitions consider its location on the route.

According to Herrmann & Schweizer (1998), landmarks localized outside the route are easily visible, just like global landmarks. This seems logical, as barely visible objects located outside the route are rarely perceived. Therefore, good visibility is very important for objects that are not on the route. Objects on the route and at nodes, supposably local landmarks, can be landmarks although they are often visible from short distances only. Lynch (1960), Kölbl (2002-2003), and Steck & Mallot (1998) differentiate local and global landmarks according to the landmark's visibility.
Finally, another possibility to differentiate various kinds of landmarks is to consider its **creation**. Böhme (2003) distinguishes naturally and artificially created landmarks while Kölbl (2002-2003) gives examples of naturally created landmarks.
A subgroup of artificial landmarks are explicitly labeling objects that are described by Sorrows & Hirtle (1999) as example for semantic attraction. Explicitly labeling objects are e.g. sign-boards and signposts. They are usually explicitly created to facilitate navigation and are in most cases less equivocal than other landmarks.
Most objective features are mentioned in only two definitions, whereas the feature visibility is mentioned in four definitions which indicates its particular importance. Seven out of nine definitions mention objective features twelve times altogether, whereas all definitions mention subjective features.

Subjective features

Subjective features are cited much more often, i.e. 21 times altogether. This reinforces the importance to consider subjective aspects.
Another example for semantic attraction described by Sorrows & Hirtle (1999) is the cultural, historic attraction. The landmark's meaning for the observer and his associations with it are other important characteristics facilitating its remembrance. However, it requires implicit knowledge about the culture specific meaning of an object. Only three authors, Lynch (1960) and Herrmann & Schweizer (1998), note that the existence of a **legend** or familiar function of an object enhances its probability to be remembered. People associate legend or known function (e.g. concert hall) and perception which enables them to remember the object easily. Actually, **remembrance** is the prerequisite for an object to be used as landmark. Only three definitions (A, C, I) explicitly note this aspect, but it is supposed that the other authors imply this feature as self-evident or regard it as a consequence of

some of the other features, i.e. a distinguishable object at a node is easily remembered.

Furthermore, most definitions emphasize that the object in question should be distinguishable from its surroundings and useful for navigation. Thereby, some definitions specify how landmarks are used. Werner et al. (1997), Sadalla, Burroughs & Staplin (1980), and Lynch (1960) emphasize that landmarks function as points of reference or basing points.

Landmarks as points of reference

The terms node, anchor point, basing point, and point of reference are frequently used in the literature, but rarely defined. Most authors employ just one of these terms, however, the contexts of use are quite similar. According to my interpretation, a node objectively describes a meeting place of at least two ways/routes. This structural attraction is also explained by Sorrows & Hirtle (1999) who distinguish nodes and edges, two components that are described by Lynch (1960) as well. They describe nodes as decision points like e.g. crossroads or squares. A node's connectivity is thereby important, i.e. the higher the number of ways leading to or away from a node, the rarer it is and the higher its importance. In addition to these objective criteria, a node's importance depends on the actual needs of the navigator. Nodes that become decision points on the navigator's route rather qualify for landmark in this specific situation.

The importance of edges (e.g. rivers, big roads) is related to the effort necessary to traverse them. Nodes and edges structure space, e.g. to the left of the Rhine or to the right of the Rhine. Beyond the faciliation of navigation, structuring space is an important function of landmarks (Elias, 2002).

By contrast, the anchor point, basing point and the point of reference are the result of somebody's subjective decision to use a certain point/place as a basis to estimate another object's location or for further orientation and navigation. According to Elias (2002), anchor points are especially useful for route descriptions. An anchor point is a place to which the route description returns again and again. Once introduced, it is a basis/starting point for further descriptions. Definitions including this aspect concurrently indicate the use of landmarks.

Use of landmarks

Landmarks are used for navigation and orientation purposes. Landmarks contribute to orientation in space, because they facilitate orientation and navigation at potential decision points and further confirm the route. Local landmarks are particularly important at decision points. On the one hand, they help to make a decision because route decisions are often associated with it, e.g. I know that I have to turn left at the bakery. On the other hand, landmarks confirm a navigator's route choice, e.g. seeing the bakery, I know that I'm still on the right track. Empirical results confirm the importance of landmarks as way-finding aids. For example, Jansen-Osmann (1998) who had subjects navigate in an actively explored virtual environment confirms the importance of landmarks. Subjects learnt the route with landmarks significantly faster than the route without. These results are confirmed by Tlauka & Wilson (1994) who investigated the effects of landmarks on route-learning in a computer-simulated environment and found better route knowledge acquisition in the landmark group compared to the non-landmark group.

Among the cited definitions, definition F notes landmarks as aid to determine the actual position of a ship in coastal navigation. Böhme (2003) describes in definition G that landmarks are good for topological route planning and development of cognitive maps. Herrmann & Schweizer (1998) consider landmarks to be useful for orientation and route confirmation.

Steck & Mallot (1998) explain the different uses of local and global landmarks. Local landmarks serve for actual route decisions. Global landmarks complete by providing an allocentric frame of reference and direction knowledge. Global landmarks, like e.g. a high building, may be used to orientate within larger territories, especially if those are rather complex.

1.4.4 Operational landmark definition

Within this paper, the term landmark is used for objects complying with the following criteria *(definition J)*. Certain features have to be fulfilled, whereas others enhance an object's probability to be identified as landmark, but are not essential.

The objective criteria significantly increase the probability that subjective features like distinguishing, remembrance, and use are complied. This probability is increased if the object contrasts with its environment, is located at a node, and is easily visible from short or large distances (local and global landmarks). Most of the landmarks provided in our experimental area are local landmarks. Further objective criteria are related to creation and movability. Landmarks can be created naturally and artificially. In addition to stationary objects, non-stationary objects may be included into the landmark definition if they are moving slowly and regularly or if the appearance indicates that the object is unlikely to be moved soon.

To continue with the subjective criteria, the object has to be distinguished from its environs, be remembered and be used for orientational and navigational purposes. Thereby, it may be used as a point of reference or simply as confirmation to be on the correct route. The existence of a legend or meaning relating to the object increases the probability to be remembered.

The higher the percentage of people using a landmark, the better it is supposed to be. Nevertheless, as explained above, personal knowledge and concepts have an important impact on the perception and selection of landmarks. For example, a certain kind of rarely existing tree can be a landmark to a botanical expert, whereas a layperson may only recognize a tree without distinguishing it from other trees. Therefore, interindividual differences in landmark identification have to be considered. Once at least one subject uses an object as a landmark for his/her navigation, this object is a landmark for this subject / these subjects.

1.5 Routes

A route is a possible connection between two or more locations that can be imagined or actually taken.

This connection can, but does not necessarily have to be the shortest connection between these locations. In pathless areas like in the mountains or on the water, a connection becomes a route by practically using it (abstract route). Of course, routes can also be fictive and imagined. Nevertheless, a route is characterised by the possibility to take it.

Especially if someone has taken a route only a few times and perceived it when moving always in the same direction, it does make a difference if he/she is asked to proceed from previous start to goal or inversely. This person will find it more difficult

to proceed from previous goal back to the start than to proceed in the trained direction. Schweizer, Herrmann, Janzen & Katz (1998) call this phenomenon route direction effect. The direction of perception is internally represented as a part of the structure of spatial information. According to Neisser (1974), spatial contiguity is the basic principle of cerebral organisation. The temporal sequence of cues is represented internally. Herrmann, Buhl & Schweizer (1995) confirmed the route direction effect in priming experiments. The priming effect in the forward direction (related to the direction of spatial knowledge acquisition) was clearly higher.
Furthermore, Herrmann & Schweizer (1998) found that subjects use significantly more low-specifying localizations if the sequence of localizations does not correspond to the sequence of route learning. This is probably caused by the interferences between learning and reproduction sequence which increase the cognitive effort for high-specifying localizations.

Supposedly, the reason for better remembrance of and navigation on a route in the trained direction is that some useful navigation strategies are based on the movement direction. For example, many people remember a landmark or view seen from a certain perspective which changes once moving in a different direction. Therefore, it is first more difficult to recognize the landmark or view when coming from another direction and second, the associated route continuation (e.g. to turn left/right) when arriving at this point has to be transferred. This transfer is necessary as well in case people use the route sequence strategy. In that case, they have to inverse the right/left turns and additionally change the whole sequence.

If the navigator disposes of survey knowledge of the area (e.g. resulting from previous experiences or map studies), he/she can decide on one of the possible routes. Especially when going repeatedly from the same starting point to the same goal, like the way from home to school or to work, many people think consciously about the best route according to their personal needs and preferences. Usually, navigators do not only want to arrive at their goal, but they want to take the presently best route.

There are various criteria influencing decisions for a certain route:

The best route may change with time of the day (e.g. regular traffic jams at certain times cause some people to evade the concerned roads, likewise dangerous suburbs may be avoided at night), with seasons (e.g. snow film on less frequented roads in winter) or with present weather conditions (certain weather conditions, e.g. overflooding, make it difficult or impossible to use a route).

Previous knowledge of the area should be taken into consideration. The first three criteria described can only be considered in case the navigator disposes of good information or a large number of experiences with travelling in this area.

If someone has only poor knowledge of an area or has to describe a route to someone new to the area, he/she should rather choose a route that is simple to remember or easy to describe. Simple routes feature a low number of turnings and therefore a low number of decision points. These are often main roads that cannot be missed and often additionally dispose of large signboards. Furthermore, many people know the main roads of an area, so if someone has to ask for the way at various points of the route, main roads or junctions are well-known and therefore good intermediate goals to ask for.

Another important criterion is the amount of time necessary to proceed from start to goal. Thereby, both the route length, possible moving speed and the number of occasions where one may have to stop (traffic lights, stop or give way signs) add up to the time needed.

The importance of the time aspect mostly depends on the next criterion, the actual situation of the navigator, i.e. his/her reason for navigation.

If someone is in a hurry, he/she will rather choose a fast route even if it may include disadvantages, like less beautiful views or more expensive fees (e.g. to use a tunnel or faster means of transportation). On the contrary, if someone is on vacation and has lots of time to get from one place to the other, he/she will likely decide for the most beautiful route including views on a nice landscape and interesting sights on the way.

Finally, decision possibilities for a route are limited to the means of transportation available. When going on foot, by bike or by car, there is a large choice of routes although some streets may be limited to pedestrians and bikes, whereas motorways are limited to cars. So, changing the means of transportation may change the route. This is why giving a route description for a certain means of transportation that the describer him/herself never uses in this area, is quite difficult. For example, a biker who may use one-way streets in the inverse direction, pass barriers for cars, etc. has to consider these different movement possibilities than choosing a route for the asking car driver.

However, when using public transportation, choices are definitely limited to the bus, tram or train routes. Thereby timetable connections may be more important than the actual route length.

Often people cannot only choose the route, but also the means of transportation. Thereby, usually time needed, price, effort, and comfort are considered.

1.6 Cognitive maps

1.6.1 What are cognitive maps?

Perception and processing of spatial information is a cognitive construction process developing a cognitive map in our minds (Barkowsky, 2001).

The term cognitive map was shaped by the field theorist Tolman (1948), who had rats train routes in a maze. He assumed that spatial experiences lead to a complex mental representation of the environment and, indeed, he found that the rats' navigation performance could not be explained entirely by elementary stimulus-response patterns that were predominant at that time. That is to say, the rats did not focus on stimulus-response triggered training of the sequence of movements, but trained spatial relations and structures. This was manifested in various experiments. For example, after several non-rewarded trials with high error scores, the rats managed to retrieve the reward (food) right away once it was available, i.e. they knew more than they evinced (latent learning). Another finding was that rats found new shortcuts to accelerate their arrival at the expected reward, i.e. they were able to connect trained routes by unknown paths. Thus, they must have had an internal representation of the environment, the maze.

A cognitive map is a mental representation of spatial knowledge in terms of survey knowledge. Survey knowledge exists if shortcuts and bypassings, i.e. unknown but useful connections between different locations or routes, are found. Even if some variations in the specific routes or in starting / final point are made or if the map is rotated, the subject will still find his/her way (Tolman, 1948) independent of the subject's present position. In addition, performance of direction estimations and of beeline distance estimations, e.g. between two locations on different routes, improves. If someone is able to accomplish one of those actions described above, I will assume that this person disposes of a cognitive map of the area in question (operational definition). The two experiments described in this thesis investigate if subjects base their navigation successfully on direction estimation (first experiment) and if they are able to give good beeline direction estimations between two locations that cannot be seen from each other and that are not connected by a straight path (second experiment).

A cognitive map represents our specific understanding of the world and is used mainly for orientation and navigational purposes, but also for other aspects, like choice of residence and planning itineraries (Downs & Stea, 1982). Cognitive maps structure and simplify spatial experiences (May, 1992). Unlike in reality, some objects, e.g. landmarks, may be depicted larger than others, consequently not representing their real size. This is not necessary, though.
Contrary to that, Siegel & White (1975) compare cognitive maps, which they call images, and paper maps and conclude that the term "cognitive map" is misleading. They argue that these images are no maps, because images do not feature typical map characteristics. For example, they criticize that images are fragmented. To my mind, maps are not complete neither, because they focus on specific kinds of information varying with its scale and aim of use, e.g. different kinds of roads for the car driver, bike lanes for the biker, and playgrounds for families with young children. Thus, I consider spatial survey representations as maps with areas of more and less detailed representations. Furthermore, Siegel & White (1975) argue that images are distorted. However, maps are somehow distorted as well, as they distort sizes (e.g. streets are often very broad which does not represent their original sizes) or, in case of maps representing systems, e.g. subway routes, routes are usually straightened and simplified. I suppose that my map definition is broader than the one by Siegel & White (1975), so that our differing assumptions may start at this level.

Nevertheless, I agree with Siegel & White (1975) on the functions of the image or cognitive map. First of all, it facilitates orientation and movement within the larger physical environment and enables people to find their way. In addition, an image or cognitive map helps to organize experiences and activities by providing a “general frame of reference within which the individual can act, or to which he can attach his knowledge” (Lynch, 1960, p.126).

Tolman already differentiated strip maps from comprehensive maps and searched for their conditions of development (see Chapter 1.6.3). Often, people use several cognitive maps featuring different abstractive levels and standards in order to resolve spatial problems (Tversky, 1993).

1.6.2 The cognitive mapping process

The cognitive mapping process is interactive, i.e. actual spatial perceptions (bottom-up processes) interact with existing knowledge, concepts and expectations (top-down processes). People already do have an imagination/ a vision of an unknown environment before actually entering it. These top-down processes are one reason for interindividual differences in spatial knowledge acquisition and enable us to quickly orientate in an unknown, but principally familiar environment. However, prior expectations may also complicate the learning process if they superimpose actual experiences, but turn out to be misdirecting for the environment in question. For example, in our experimental environment, there is a maypole that is not located in the center, but at the very edge of the campus. Some subjects disposing only of a vague remembrance of the maypole’s location, went back to their familiar concept ‘a maypole is located in the center’ and searched for the maypole there. If they could not find the maypole in the center, most of them did not question their concept, but thought that they have not found the center yet.

The formation of cognitive maps does not depend on visual cues only. Downs & Stea (1982) cite a few examples confirming that blind people are able to develop cognitive maps of their environment, as well. This illustrates the importance of the other senses, like locomotion, tactile sense, olfactory sense, and sense of hearing.

The perception process is highly selective and so is the choice of suitable elements to be inserted into the cognitive map. Downs & Stea (1982) describe selection according to the functional meaning and to discernability. The question about selection strategies leads to the question "What are the characteristics of a landmark?" which was discussed in Chapter 1.4.1.

The process of creating a cognitive map is influenced by:

1. The observer
   a) Personal characteristics (via top-down processes)
      - Personal concepts (what does a city center, a campus, etc. …look like)
      - Favored navigational strategies
      - Personal characteristics (age, abilities, practice, interests, profession – e.g. an architect may focus on the architecture of the building whereas a gardener may focus on vegetation;)

   b) Situation characteristics
      - Attention
      - Training context and expectancies (will I have to orientate myself again in this area?)
      - Means of spatial knowledge acquisition
        Direct experiences with the area: time spent there, routes traveled; mediated experiences: route descriptions, maps, narratives;
      - Movement parameters (foot, bike, car, bus, underground, plane, etc.) (Downs & Stea, 1982)
      - Previous knowledge about the area
      - Location and distance of the observer's home town to the designated area (Lloyd & Heivly, 1987)
2. The area in question
   - Specific characteristics, e.g. landmarks, traffic routes, edges (Lloyd & Heivly, 1987)
   - Size
   - Topography

Concerning the factor "location and distance of the observer's home town to the designated area", I want to cite a study of Whittaker & Whittaker (1972) who had groups from different countries sketch a map of the earth. They noted that most subjects indicated their own country disproportionally large. Moreover, the closer another country is to the subject's home country or the more important it is (e.g. politically or economically), the more probable that this country is depicted. The authors call this phenomenon geocentrism.

With increasing knowledge of the area, the cognitive map usually becomes more detailed and more accurate. Cognitive maps may be changed by subsequent experiences (see e.g. Downs & Stea, 1982, p.299).

To sum up, cognitive mapping does not mean copying, but selecting, constructing, and configuring.

Concerning the quality of a cognitive map, the decisive aspect is that it includes the combination, kind and minimum of elements necessary for personal orientation and navigation.

1.6.3 Development of cognitive maps following the main sequence

The development of cognitive maps is incremental (Gluck, 1991), i.e. at the beginning, cognitive maps are fragmentary, then, with further spatial experiences, they are completed and substantiated. However, several authors (e.g. Thorndyke, 1981; Siegel & White, 1975) assume that spatial knowledge acquisition follows a main sequence of landmark, route and survey knowledge in ascending order. This main sequence (although faster) corresponds to the development of spatial understanding in childhood.

First, most people turn their attention to distinctive points and objects, called landmarks, and remember particularly those. Landmarks are the first elements to be included into spatial representations. At that early stage, we speak of **landmark knowledge**. People can describe single features of the route, but most of them are not able to retrieve the route alone.

Further on, these points are connected by the most frequently traveled routes. Route knowledge consists of the familiar routes connecting junctions and/or landmarks. **Route knowledge** is acquired gradually and therefore features a sequential structure. The sequence of landmarks and turnings is used to proceed on the entire

route. People are able to retrieve the route and the goal and possibly to go back and find the starting point.
At both levels, spatial knowledge is egocentric, i.e. depending on the actual position and viewing direction of the navigator, whereas at the third and last distinguished level, **survey knowledge**, spatial knowledge is allocentric, i.e. independent from the individual. In order to gain an overall picture, landmarks and several routes are integrated in a more and more complex network. Survey knowledge exists if shortcuts and bypassings are found, good direction estimations and beeline distance estimations are made, and if some variations in the specific routes do not prevent subjects from finding their way (Tolman, 1948).
When orientating and navigating, people use their present spatial knowledge to develop an action plan. The navigation strategies are based on the spatial information available. Thus, a subject disposing of survey knowledge can choose from a larger number of strategies than a subject disposing only of landmark or route knowledge. The first experiment investigates the navigation strategies used by subjects and concludes on the knowledge basis of strategies.

Tolman described 1948 strip maps and comprehensive maps corresponding to the above described route and survey knowledge. Besides the amount of experiences with an environment, Tolman names further **conditions influencing the development of maps.**
“Strip maps rather than broad comprehensive maps seem to be induced: (1) by a damaged brain, (2) by an inadequate array of environmentally presented cues, (3) by an overdose of repetitions on the original trained-on path and (4) by the presence of too strongly motivational or of too strongly frustrating conditions.” (Tolman, 1948, p.205ff)
Survey knowledge may be acquired by map studying as well. In this case, survey knowledge can precede route knowledge. Herrmann, Schweizer, Janzen, & Katz (1997) call it map knowledge. However, maps are not always superior to signboards indicating route knowledge. Butler, Acquino, Hissong & Scott (1993) investigated wayfinding by newcomers in a complex building comparing various navigation aids. They found that signboards proved to be better navigation aids than “You-are-here-maps”.

1.6.4 Query of the main sequence and proposal of a sequence of dominances

Thus, getting to know an unfamiliar environment, there are two levels of spatial knowledge preceding the development of cognitive maps. In my opinion, these different levels follow each other with regard to their dominance in the navigation process, but do not exclude one another. So, landmarks may remain an important strategy, even in a well-known area, whereas the direction strategy may already be used at first contact with an area.

In addition, there are different mental representations even within one phase, e.g. route knowledge often includes the sequence of landmarks, a film-like optical flow, or additionally the sequence of viewpoints (Herrmann & Schweizer, 1998).

Likewise, Ruddle, Payne & Jones (1997) found that route and survey knowledge improve at the same time and to the same degree. Thereby, they agree with Holding & Holding (1989) and Hirtle & Heidorn (1993) who showed that route and survey knowledge can be gained simultaneously.

Aginsky, Harris, Rensik & Beusmans (1997) even describe experiments suggesting a learning sequence opposite to the main sequence, i.e. some survey knowledge was the prerequisite to achieve landmark knowledge.

In their own experiment, Aginsky et al. (1997) had subjects learn a route in a complex virtual environment. Afterwards, subjects were asked to recognize scenes and route, to detect building changes on the route, and to draw a sketch map. With regard to the structure and quality of sketch maps, three groups of subjects could be formed. Considering the other two tests, there were consistent differences between one group (global structure) and the other two groups (no or local structure) of sketch mapping corresponding to a spatially dominated (mental map that is continuously updated) and a visually dominated (action only after recognition of decision points along the route) wayfinding strategy. Thus, subjects' differences in spatial behavior reflect rather strategy differences than stages in spatial training.

Besides, Hartl (1990) shows empirical evidence that route knowledge can precede landmark knowledge. Aginsky et al. (1997) doubt if landmarks can ever be conceived independent of context and routes.

Montello (1998) proposes an alternative model which describes a quantitative (rather than a qualitative) evolution of spatial knowledge acquisition. This corresponds to Devlin (1976) who had new residents draw sketch maps after two weeks and again after three months of residence. The maps drawn after three months were elaborations of the first, already quite accurate, maps. The first and second maps were not qualitatively different, which supports the concept of a quantitative evolution of spatial knowledge acquisition.

The question for the time of development of cognitive maps is related to the question for the definition of cognitive maps. In addition to the above cited definition, some authors propose different kinds of cognitive maps.

For example, Mallot & Steck (2000) distinguish two different types of cognitive map organization:

- Topological organization: configuration knowledge, particularly large areas that have not been explored extensively
- Metric organization: includes additionally coordinates of all known locations, good distance and direction estimations possible; may result from proper motion estimation, depth perception or configuration analysis;

There are different opinions to when we can start speaking of a cognitive map. According to Siegel & White (1975), getting to know a new territory means first acquisition of landmark and route knowledge and with increasing experience the acquisition of survey knowledge (see previous chapter).

I agree that at the beginning, route knowledge is developed more easily, at least if you are moving (actively) through the terrain having a film perspective. But I think that this does not exclude the acquisition of survey knowledge. This early cognitive map is completed with information acquired during further experiences with this territory. In my opinion, both processes overlap, with a dominance of landmark and route knowledge at the beginning.

1.6.5 Impact of previous knowledge and concepts

Moreover, I argue that even before actually entering a field, people already form an idea of what to expect. In a German village for example, most people may expect a church and a market place, both located in the center.

Even if the expected objects do not actually exist, they may nevertheless be added to the mental representation (Downs & Stea, 1982).

Brewer & Treyens (1981) speak of cognitive schemata about relevant, recurrent spatial structures, which influence the development of spatial knowledge. Herrmann & Schweizer (1998, p.159) describe the schemata as information structures containing slots that can be completed by actually perceived information. These schemata reduce cognitive effort and are mostly helpful for orientation and wayfinding (e.g. Zimring & Gross, 1991), but also important as a common basis of implicit knowledge when someone describes a route or gives directions to another person (Herrmann & Schweizer, 1998). Furthermore, these schemata may accelerate useful classification and structuring which is essential with regard to the number of stimuli to be processed. Nevertheless, existing schemata can also distort the perception of the unknown, they may lead to false classifications that are often difficult to reverse and distort our perception of the world.

Previous personal experiences in similar environments as well as information given by the mass media or other sources provide previous knowledge about a terrain. This knowledge makes us search for the expected elements on-site, thereby influencing the selectivity of our perception process. Furthermore, we associate features of the environment with our knowledge about these elements. We integrate previous knowledge and expectations (top-down processes) with the perceived facts (bottom-up processes) (see e.g. Downs & Stea, 1982, p.317; Kretschmann, 1986).

1.6.6 Elements of cognitive maps

The different pieces of information that form a cognitive map have been categorized by several authors (e.g. Tolman, 1948; Bruner, Goodnow & Austin, 1956; Lynch, 1960; Siegel & White, 1975; May, 1992).

On a general level, Bruner, Goodnow & Austin (1956) categorize objects according to identity and equivalence. The identity category refers to different manifestations of the same thing, i.e. particular features are highlighted and form the identity, whereas the equivalence category refers to the formation of groups of similar features. In order to define an equivalence category, criteria are determined that are the basis for assignments to a certain group/class. Thereto, similarities are emphasized whereas differences are neglected.

These two categories also form the basis of cognitive maps according to Downs & Stea (1982). Orientation relies on the match of the environment with an identity category. Thereto, unknown places and objects are compared to known places and objects. In the course of further spatial experiences, categories and criteria may be modified. This comparison is the underlying process of all steps characterizing the process of finding one's way.

More specifically, Lynch (1960) distinguishes five components in large-scale urban areas. He wanted to know which elements people use to orientate in their home town and had his subjects living in Los Angeles, Boston, or Jersey City draw a sketch map of their town, make descriptions, and participate in an interview. His data analysis revealed the following five components:

1. Paths
   Channels used to move on, e.g. streets, railways, canals;
2. Edges
   Linear elements that are not considered paths, usually boundaries separating two areas, e.g. coasts, walls, borders of specific land-use areas;
3. Landmarks
   Optical points of reference, contrasting (significantly) with the environment, e.g. buildings, hills, objects;
4. Nodes
   Strategic points of a city, accessible and intensively used / frequented, usually points where people to have decide on how to continue their route (strategic nodes), often also starting point and/or destination, e.g. crossroads, street corners, familiar places where specific people meet (thematic nodes);
5. Districts
   Middle sized or big segments of a city that can be entered, recognizable by its own character

One component may have differing significations, e.g. in different cities or for different road users. A central place in a city may signify a district in a smaller or middle-sized town, whereas it may be a node in a big city. Another example is the highway that is a path to move on for the car driver whereas it means rather an edge for the pedestrian who might have to look for a tunnel or bridge to cross it. Thus, these components are no isolated elements, but interact with their environment and influence one another's effects and significations. Two components may reflect each other and thereby enhance their effects, or conflict with each other and thereby destroy each other's effects (Lynch, 2001). For example, a landmark taking a strange effect in a district may affect its continuity, but it is also possible that it intensifies the district's uniformity.

Urban areas are suited for investigating these elements on a limited area.

Appleyard (1970) found all the above described elements in the maps that his subjects produced of their home town Guayana (Venezuela). He classified paths and nodes as sequential elements, which were more often used to describe Guayana, and landmarks, districts, and edges as spatial elements. Furthermore, the different types of maps produced show that there is an "extraordinary variety of methods that people use to conceptualize cities" (p.109) or/and to draw one's conception on a piece of paper.

Kosslyn, Ball & Reiser (1978) showed that reaction times correspond to distances of starting point and final point on the cognitive map. They had subjects learn the map of a fictive island. Then, a subgroup was asked to imagine the whole island and to concentrate on a certain location without losing the imagination of the whole island. Afterwards, they were asked if other stated places are located on the island or not. The authors measured reaction time depending on distance between starting and final point and found a linear connection. This did not happen at the other subgroup who concentrated on one location only.

1.6.7 Measurement of cognitive maps

The design of cognitive maps is difficult to apprehend, because most methods influence results significantly in various aspects.

For example, the apparent lack of a certain element in a subject's cognitive map can stand for various facts: the subject does not know about this element, knows about it, but cannot remember it without other stimuli normally present in the field situation, cannot represent it in the asked way or is not motivated to try to do so, etc.
Inversely, the subject's ability to navigate or find a goal in a terrain does not necessarily imply the ability to draw a sketch map of it (see e.g. Gale, Golledge, Pellegrino & Doherty, 1990).
Like this, the investigation of cognitive maps can be confounded with the subjects' abilities and motivation.

1.6.7.1 Focus of attention

Cognitive maps are represented differently depending on the actual focus which results from different needs and aims of its use. For example, there are two people who just arrived at the train station of a town they had visited a few times before. One person wants to navigate to a friends house (focus navigation) and will consequently activate particularly relevant landmark and route information, whereas the other person who wants to do some sightseeing this time (focus sightseeing) will probably think about the location of the city center or historic section of town and interesting landmarks. Therefore, both visitors activate a specific kind of cognitive map or specific aspects of the existing map. The focus of attention selects cognitive maps and influences the information activated.
This aspect makes it difficult to think of a cognitive map as a whole. At a certain point in time, we often use only a part of the spatial knowledge our cognitive map provides, e.g. we search for a specific landmark.
With regard to experiments investigating cognitive maps, the impact of the actual focus means that the context or cover story provided during training and test phase has a meaningful impact on what kind of spatial information subjects adopt and express.

1.6.7.2 Influence of the inquiry method

The asked manner to present one's knowledge encourages the subject to reorganize his/her spatial knowledge and to adapt it in order to present it in the questioned way (to navigate, to estimate directions or distances, to draw, to verbalize, or to build).

This is especially problematic if the researcher wants to learn about the design of a cognitive map, but learns probably more about its adaptability and the resulting structure.
Moreover, previous experiences with the method may influence the appearance of the cognitive map presented by the subject. Particularly the sketch map method is affected by this problem: subjects may adapt their map to the kind of map he/she knows, so the appearing structure and elements may tell us probably more about the paper maps the subject used to deal with than about his/her cognitive map.
Verbal inquiry methods are concerned in a different way: the formulation of the questions triggers the answers, so in this case the ideas and experiences of the researcher are influencing the results; Furthermore, subjects face the linearization problem (Denis, 1996; Levelt, W.J., 1982), i.e. they have to decide on the sequence of their depiction.
These factors add to the usual problem of the subject's desire to satisfy the experimenter and to fulfill his expectancies.

1.6.7.3 Limitation by the inquiry method

The possible output is limited to the articulation possibilities of the questioned way of presentation.
For example, some aspects cannot be verbalized easily (e.g. directions without knowing the point of compass), whereas others are hard to draw (e.g. altitudes, or special aspects of landmarks). Therefore in a sketch map task, I would expect the presented cognitive map to include more elements that are easy to draw, whereas *at* a verbal description task, I expect a dominance of elements easy to verbalize.
If the question is unspecified, like the sketch map and verbal description task, most subjects tend to express only the aspects that are easy to represent. Of course, subjects disposing of excellent drawing abilities or high eloquence may be able to draw or verbalize all aspects easily. The criterion for usage is not the mere possibility to e.g. draw something, because many subjects are inclined to go the easy way - depending of the subject's motivation of course.
Comparing interindividual results, we have to take into account the individuals' abilities with respect to the method used, e.g. to draw, build, verbalize, etc. (see e.g. Downs & Stea, p.296)

The number of possible **dimensions** of the representation is often reduced as well. In verbal descriptions people often use only one or two dimensions, because they are unable or it's hard for them to create a 3D description this way. Sketch maps and the 'toys world' method are usually 2D, but they can reach 3D if e.g. hills, mountains, or the different height of buildings are included. This may be easier when using the 'toys world' method with differently sized pieces. In addition, subjects can easily test various variations of arrangement and change it if necessary. When drawing, most subjects do not dare to change things once it is drawn. Cognitive maps can have even four dimensions: length, width, height, and time;

1.6.7.4 Conclusions

To sum up, the above mentioned methods give a question and representation form triggered insight into the appearance of cognitive maps. However, if we want to assess the utility of a cognitive map, comparing qualitative data is a problematic way to do so. There are large interindividual differences concerning elements needed for successful navigation and likewise, there are large differences with regard to personal navigation strategies.

In my opinion, the more objective criterion to measure the utility of a cognitive map is navigation behavior, especially navigation success. According to Downs & Stea (1982), we can assume that successful resolution of common spatial problems is a sufficient proof for the match of the cognitive map to the real environment.

In my opinion, navigation performance is an approved method to evaluate the utility of a cognitive map. Nevertheless, even in this case there are different competing criteria, e.g. success, time needed to find a goal, route used, number of times subject turned back, number of times subject took a course removing himself from the goal, or a certain combination of different criteria (see Figure 3); Of course, most of these criteria usually correlate with one another. As a consequence, we should always take into account that the change of performance measurement method or definition criteria may produce different results.

The first experiment investigates navigational success and the subjects' strategies to retrieve a goal. Information about navigation strategies is collected by two methods that also give an insight into the subjects' spatial representations: thinking aloud and strategy interview (afterwards); These methods reveal the amount and kind of spatial information available and how it is used to solve spatial problems, here finding a goal.

The second experiment asks subjects to describe routes and to estimate directions which gives further information about their spatial representations.

1.7 Navigation aids

1.7.1 Definition

Navigation aids encompass all external means supporting orientation and navigation. 'External' means knowledge that is not part of the navigator's own spatial representation.

If the navigator has no memory knowledge about the area and the route in question (e.g. if he/she has never been there and has no previous information), navigation aids can enable the navigator to find his/her way which otherwise he/she would not have found. On the other hand, if the navigator already possesses some relevant spatial knowledge, navigation aids can support the navigation process, e.g. by suggesting a better route, and may enhance navigation speed and success.

Many people prefer using several navigation aids at the same time, which may help if one aid is less precise or equivocal at a few or all decision points. However, the use of various aids may also complicate the navigation process. Several pieces of information have to be processed and, in the worst case, these aids contradict one another. At that point, the navigator has to decide on one of the aids or search for further information, e.g. to ask a passer-by.

Of course, navigators have to know how to use the available navigation aids in order to benefit from them, which might be easy in case of signboards, more demanding with maps and requires specific training for most technical systems.

There are various kinds of navigation aids that will be described here following.

1.7.2 Route descriptions

Route descriptions can be the navigator's own notes about a route. These notes are usually picked when taking or shortly after having taken the route, presuming that

he/she already knows he/she will have to take the route again at a time when he/she might not remember the route from memory.
However, in most cases, someone else provides information about a route the navigator has not taken before. This can be a spontaneous oral description given by a passer-by on the street or a written description that may be personalised or an official journey description.
As route descriptions are the focus of the second experiment, this category of navigation aids is described more in detail in Chapter 2.7.

1.7.3 Natural systems

The appearance of natural systems is not changed in order to increase its use for navigation. Examples are rivers, mountains, valleys, but also particular terms, like 'saddle' and 'cirque' that are not known to everybody. Steck, Mochnatzki & Mallot (2003) could show that adding a geographical slant reduces the number of navigation errors significantly.
The stars and the sun are other examples, whose popular use for navigation in former times decreases with the increasing number of other navigation aids.
Sometimes people do not look at the whole thing, but perceive and remember specific features, e.g. size of a path and path texture or the size of a village or town.
Natural systems have to be described and explained, the amount of necessary details depends on the navigator's previous knowledge.
They can function as global landmarks (e.g. mountain), borders (e.g. river), districts (e.g. island), and paths (e.g. rivers for boats).
In most cases, natural systems are good navigation aids, which are easy to find (mainly because of their size) and indicate directions unequivocally.
For example, bike tours along rivers are popular for many reasons, but also because navigating along these paths always staying close to the river is usually quite easy. Bikers know that they have to continue their way parallel to the river and its flow direction indicates the direction.

1.7.4 Artificial systems

Artificial systems are systems that have been created to facilitate orientation and navigation. These can also be man-made landmarks that were created for this reason.

Examples are signboards indicating the way to specific roads, places or areas, but also complex route guidance systems at freeways.

Another example, mainly used in rural areas, are trail markers. If the route and final point are known to the user, this can be a very easy and good orientation system. These trail marker systems therefore are usually both producer and user friendly.

Survey boards depicting the area and the marked paths should be erected at popular starting locations or at locations where people might first meet the path. This system would ensure usability also to users that do not dispose of a hiking map indicating the marked paths or information about the trail system from other sources. Even people knowing where the path leads to would benefit in order to orientate themselves where they are or to change route.

In urban environments, street names and numbers are usually good indicators of a route. Following a certain street which thus represents the route makes it mostly quite easy to keep on the right track.

1.7.5 Technical systems

In fact, technical systems are a subgroup of artificial systems, especially systems further developed. These technical systems are created in order to support navigation and many of them accompany the whole navigation process.

Some objects are part of an artificial system, others are more specifically part of a technical system. There is a further group of objects that could fall in either category according to the way they are used. For example, a lighthouse is a global landmark for a pedestrian, biker or driver, but a technical landmark for skippers.

The compass is a typical technical system used mainly in areas featuring a few number of landmarks or other structuring elements, e.g. on the mountains, in rural areas, on lakes and at sea.

A recent example are navigation systems in cars, planes, ships, and other means of transport that give instructions how to move to arrive to the programmed goal. Good

systems do not only know about the constant route network, but can react as well to present events, e.g. traffic jams, closed streets, or certain weather conditions that make a route change necessary.
Although, technical systems that are created for everybody’s use should be as self-evident as possible, many systems require thorough manual study or even special training for the user. That’s where the importance of the discipline man-machine-interaction becomes clear.

1.8 Route description

Route descriptions are a specific, frequently used kind of navigational aids. Usually we speak of route descriptions when someone explains to another person how to get somewhere. A route description could be a standardized text or sketch-map, or a spontaneous verbal description given by a passer-by who comes along by chance.
Route descriptions may be based on or include pieces of information that constitute natural and artificial systems. Even within a city, natural systems may provide useful edges, hence a route description could suggest to walk along the river or not to cross the river. Parts of artificial systems like signboards, may be included as well, e.g. “continue straight on until you find a signboard on the right indicating the way to the swimming-pool, then follow the signs”. This example shows that artificial systems can efficiently complete a route description.

1.8.1 Route illustration and route description

As indicated above, there are various kinds of route descriptions, e.g. written and verbal descriptions. In addition to the way of transferring route information from the sender (speaker) to the receiver (hearer), descriptions may be aligned to different aims. Herrmann & Schweizer (1998) distinguish route illustration („Wegbeschreibung“) and route description („Wegauskunft“) as follows (Table 2).

In the second experiment described in this thesis, I will deal with route descriptions aiming at navigation in terms of Herrmann & Schweizer (1998).

	route illustration	route description
start and goal	speaker decides on beginning and end of his description	fixed starting point (position of the hearer) and destination (hearer's goal)
hearer's aim	receive an impression of the route	follow the route to the goal
evaluation criteria	clearness and imaginativeness, depending on the specific aim and the hearer's previous knowledge of the route	stricter evaluation citeria towards route (efficient and agreeable) and description (precise, easy to remember, omitting redundant specifications)
localization sequences	static and dynamic	dynamic

Table 2: Contrasting route illustrations and route descriptions

The following two sections give a short introduction into what the speaker actually does when describing a route. In short, the speaker develops localization sequences that have to be linearized.

1.8.2 Localization sequences

Route descriptions and illustrations are developed by forming a series of localizations. A localization is the present statement of place of a person or an object. The aim is the coinciding spatial orientation of both speaker and hearer. Localizations are connected by descriptions of locations and durations. These localization sequences are sequences of single localizations in classified order.

According to the two types of descriptions, there are two different kinds of localization sequences. Static localization sequences do not refer to any actor in order to provide spatial relations. Instead, the speaker must refer to a visual focus familiar to the hearer. In contrast, dynamic localization sequences use the neutral "you" as person moving on the route or through the area to be described. Route descriptions usually contain dynamic localization sequences, whereas route illustrations may contain both dynamic and static localization sequences (Herrmann & Schweizer, 1998).

1.8.3 Linearization

Before giving a route description, the speaker conceives the route in his/her mind. After having activated the relevant information, the speaker has to put the remembered pieces of spatial information, i.e. the localization sequences, in a comprehensible order.

Giving route descriptions, the speaker has to decide on the sequence of his pieces of information, i.e. he/she has to transfer spatial configurations into a temporal sequence of verbal descriptions. This is called the linearization problem (Levelt, 1982).

Time and space are principally independent, i.e. in contrast to events, there is no natural, definite chronology for description. Nevertheless, considering route descriptions as localization sequences, the sequence of mentioning the pieces of route information often complies with the temporal sequence of the described navigation. The creation of localization sequences and their linearization relates to remembered and now imagined movements on the described route. The speaker uses his knowledge about actions and movements.

At best, the speaker begins with the localization of the hearer and then gives the information necessary to reach the second localization. After this (possibly implied) localization of the hearer, the speaker describes the important aspects of the third localization and so on, until the aim is reached (Herrmann & Schweizer, 1998). Denis (1996) describes a similar schema of ideal route descriptions. Thus, there also exists a framework for route descriptions. However, it is essential that speaker and hearer agree on the implied sequence.

There is another example for a framework. People imply that proximity in time means spatial vicinity. Although this is not always the case, it can be a useful principle providing additional information.

Another aid is the principle of space constancy which means that the hearer can rely on the location of objects or events that do not change until the speaker says so (Ehrich, 1989). When the speaker wants to suspend the principle of space constancy, he needs to inform the hearer. It is important that speaker and hearer agree on the implied sequence and on the starting point of every description sequence. There are several possibilities on choosing the starting point. The speaker can describe the whole route from one point, which is usually the speaker's present position. This strategy may serve for short or easy routes and may give a broad overview to the exercised hearer, but it may be very difficult for the hearer to transfer these pieces of information to actual decisions once moving on the route. Another possibility is to jump from one location to another. Thereby, the problem is that the hearer may not always know where the starting point actually used is located exactly. To my mind, the most promising principle for verbal descriptions is the generic wanderer who is based on continuous movements on the route (see also Chapter 1.8.5).

However, in everyday life most people do not always manage to act according to the above described ideal cases. The main reason for this is that in addition to spatial information, people have associations with specific objects or locations that have to be processed as well. These associations may pop up while the speaker is giving the route description and may cause the speaker to leave his/her orderly recitation of sequences. Furthermore, the temporal sequence is often rather reconstructed than remembered and, what is more, it is not the only principle of arrangement. Pieces of information may be also arranged according to importance.
To sum up, there is an implicit linearization framework that helps to order localization sequences. However, in everyday life its use is complicated by the existence of associations and competing principles of arrangement.

Research on the linearization topic was done by Levelt (1982) who describes two orientation types (pattern-oriented subjects use the intrinsic or allocentic system, ego-oriented subjects use the deictic or egocentric system) and three process related linearization principles:

1. Spatially adjacent objects are described successively.
2. When describing different routes with a connecting starting point, the speaker gets back to this point after each route description.

3. If there are two routes departing from a point, the shorter route is described first.

All of these principles are supposed to rely on the precept to reduce cognitive effort, i.e. speakers linearize spatial relations in a way that his and the hearer's working memory are stressed the least possible. However in practice, speakers are not always able or motivated to do so.

1.8.4 The effects of knowledge genesis

Herrmann & Schweizer (1998) show that knowledge genesis, including both cognitive abilities and the learning situation, may have a lasting effect on linearization strategies. The genesis effect comprises continuity between the learning and the reproduction situation with regard to localization (static versus dynamic) and start and final point (forward versus reverse direction). Empirical verification was achieved through an experiment with 52 students at Mannheim who acquired either survey knowledge or route knowledge (with two different starting points) about a modeled village. Results confirm the above cited assumptions, i.e. subjects with route knowledge produced mostly dynamic localization sequences whereas subjects disposing of survey knowledge produced both static and dynamic localization sequences. Furthermore, the sequence of localizations corresponds to the sequence of route learning. If subjects are asked to describe the route from the final point (of their learning phase) back to the start, they use significantly more low-specifying localizations (e.g. "the statue is near the theater" instead of "the statue is to the right of the theater"). Interferences between learning and reproduction sequence increase the cognitive effort for high-specifying localizations. Thus, most people prefer low-specifying localizations in order to reduce the cognitive effort and to avoid false statements.

1.8.5 The generic wanderer

Another possibility to linearize is to tell the hearer what you see when wandering on an imagined route (Herrmann & Schweizer, 1998). This strategy is called "generic" because of the usage of the general personal pronoun "you" instead of a designated person.

This strategy includes two phases:

1. If–part: Description of the generic wanderer’s actions / movements and thereby introduction of the second part, e.g. “If you turn around the corner, …”
2. Then-part: introduction of new objects by positioning them in relation to the generic wanderer’s visual focus

If the generic wanderer’s viewpoint doesn’t change, the speaker can omit the “If-part” and proceed with a new object. Considering this strategy from a linguistic perspective, motional and perceptive verbs and the personal pronoun “you” (sometimes also “I”) prevail. In order to ensure comprehension (between speaker and hearer), the resulting route descriptions have to be based on and concurrently restricted to conventional knowledge about spatial behavior and general standards.

1.8.6 Components of route descriptions

Some research was done to investigate linearization strategies, but only few authors describe the specific components of route descriptions. I will cite Denis (1996) who describes five classes of components:

1. action guideline (without reference to a landmark)
2. action guideline with concurrent reference to a landmark
3. announcement of a landmark (dynamically or statically, without indication of direction)
4. landmark description (in order to ensure its recognition, without mentioning its location)
5. comments (general statements and summaries) and distances

This classification focuses on landmarks and its different possibilities of use, whereas it pools other important categories, like direction and distance, with the indefinite remaining components. Our first experiment investigates if landmarks are an important, but probably not the only frequent navigation strategy. If there are indeed other frequently used strategies, I will suggest to distinguish further classes of route descriptions, e.g. direction, distance, route sequence;

MacFadden, Elias & Saucier (2003) investigated the usage of route description classes by men and women. They had 44 subjects study routes on a map and afterwards asked them to describe these routes. There were no gender differences concerning visual scanning of certain features, but there were differences with regard to the use of route description classes. It resulted that men preferred giving global direction information (e.g. north, south), whereas women based their route descriptions mainly on landmark and route sequence information.

1.8.7 Quality factors of route descriptions

Denis (1996) searched for the quality factors of route descriptions. On a university campus, he asked subjects to describe a route and presented all the pieces of information to experts who selected those pieces which, in their opinion, formed ideal route descriptions. These ideal route descriptions were evaluated empirically by comparing them with the first route descriptions produced spontaneously by subjects. It resulted that strangers in the campus found their goal better with the ideal version which can be characterized by a minimal number of necessary localizations, omitting repetitions and unnecessary details. Accordingly, the mention of many landmarks and details does not improve the quality of the description. However, the sequence of decision points needs to be complete and contain the crucial cues.

By contrast, route illustrations may include both detailed descriptions and the speaker's comments and evaluations in order to enable the hearer to gain a good impression of the described route or area (Herrmann & Schweizer, 1998).

Another important aspect that several authors emphasize (Waller & Harris, 1988; Herrmann & Schweizer, 1998) is the adaptation of route descriptions to the (assumed) abilities of the hearer. Waller & Glenn (1988) showed that children already at the age of eight made spontaneously adjustments for younger hearers. Furthermore, the authors evaluated the given route descriptions by investigating its linearity and concluded on quality criteria similar to the ones described above. Of course, route descriptions also depend on the speaker's abilities.

The characteristics of good route descriptions are also one of the main research aims of my second experiment that will be described in this paper. In addition to the quality of information, I investigate the effects of different kinds of route description components.

1.8.8 Written versus verbal route descriptions

The route descriptions investigated in the second experiment are representative for written descriptions of urban environments. They are not typical for rural areas where popular features like buildings and paths are rarer. Furthermore, there are specific differences between verbal and written route descriptions (Taylor & Tversky, 1992, in Herrmann & Schweizer, 1998, see Table 3 below).

	written route descriptions	verbal route descriptions
storage of interstages	Can be saved/memorized externally, thereby they are always available and evaluable	Have to be saved internally and actualized time and again, given parts are hardly reversible
breaks	Speaker can decide on the speed of production and make breaks	According to most communication conventions, the speaker is expected to speak continuously
cognitive effort	lower	higher

Table 3: Comparison of written and verbal descriptions

To sum up, in case of written descriptions

- Just the complete product counts
- The speaker can decide on the speed of production and make breaks, which decreases his/her cognitive effort

Another advantage of written descriptions is that the information can be saved externally. Contrary to that, verbal route descriptions have to be remembered by the hearer. Psychology of learning and memory processes states that usually people remember up to 7+-2 chunks (Miller, 1956). Thus, the pieces of information included into a verbal route description should not extend this number.

Nevertheless, when listening to a route description, the hearer has the possibility to ask further questions if he/she does not understand what the speaker says. In case of a written description, this is more difficult if the author is not available any more.

1.9 Orientation and navigation research methods

1.9.1 General considerations

Comparing the results of various spatial cognition studies, we have to consider the kind of spatial information provided and the different methods that have been used for spatial knowledge acquisition and performance measurement, as well as the characteristics of the group of subjects (see Figure 1). Differences in results between studies, are likely to (at least partially) result from the difference of methods used. For example, poorer navigation performance in a specific study may result from environmental features (e.g. less landmarks), lower training possibilities (e.g. smaller flowfield, more complex environment), stricter performance criteria (e.g. less time to retrieve the goal successfully), and/or a lower degree of relevant subject characteristics (e.g. less navigation experiences or higher field dependency) than in another compared study.

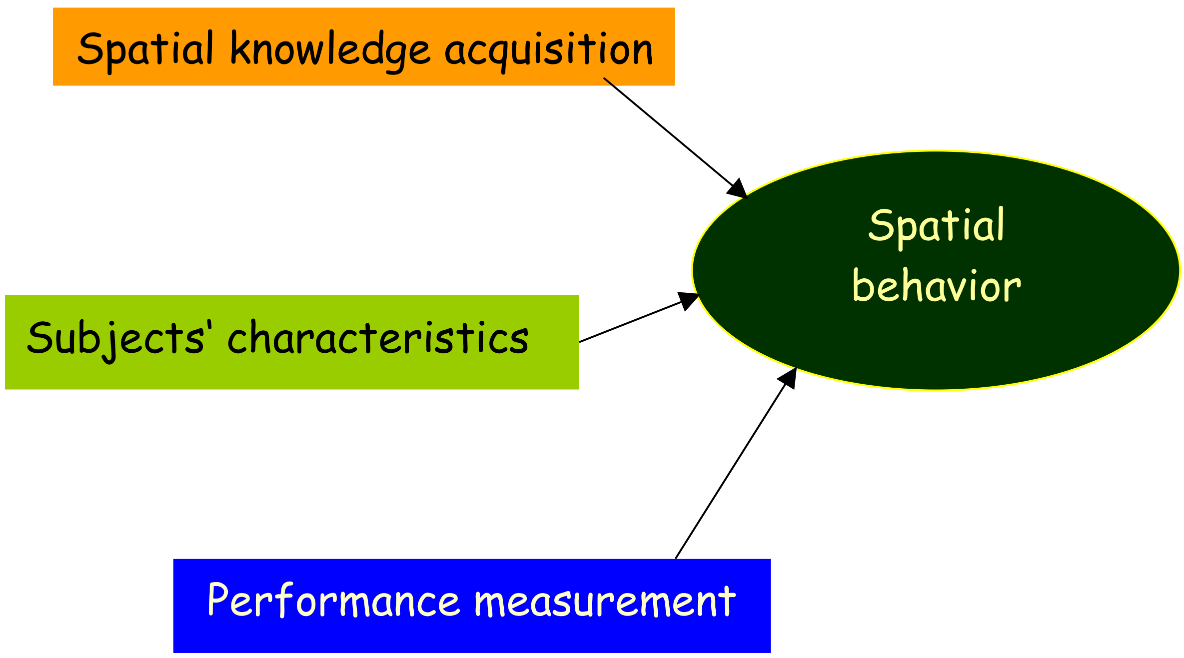

Figure 1: Main factor groups influencing spatial behavior

Therefore, when planning a new investigation, we should consciously select a means of spatial knowledge acquisition and one or more compatible performance measurement methods. Thereby, it is important to know what type of spatial knowledge we want to focus on and if the results will be compared with specific studies. With regard to external validity, we have to decide to what kind of variable operationalizations, situations and people we want to generalize our results. The mindmap-like organized Figures 2 and 3 give an overview of possible methods for training and test phase. The question if virtual realities realized by means of a vision dome produce results comparable to those in real environments, is one of the focal points of this work. With regard to subjects, I suppose that the prevailing sociodemographic factors like education, gender and age have less impact on spatial cognition than practice of activities including orientation and navigation, and field dependency (see Figure 4).

1.9.2 Advantages and disadvantages of laboratory and field research

Spatial cognition research is performed in different environments. The chosen environment affects results and quality factors of the investigation.

1.9.2.1 Laboratory experiments

Laboratory experiments allow for systematic variation with respect to configuration and details of the provided environment. In addition, they provide constant research conditions (independent of disruptive factors like weather, daytime, changes in the environment, etc.) and exact data recording (enhancing reliability), and therefore provide high reliability and internal validity.

Virtual realities in particular feature high and economic variation possibilities of the virtual environment, which may represent a real or a notional environment. Moreover, virtual realities provide the possibility to present the environment in different perspectives (e.g. film versus overview) and with various interaction opportunities for the observer.

Nevertheless, human spatial behavior in laboratory settings cannot be generalized easily to everyday behavior in real settings. Thus, laboratory methods lack external validity. Furthermore, laboratory settings provide only a limited number and type of cues. Laboratory settings in spatial research are often restricted to visual information, whereas in the field, various sensual impressions or a certain combination of visual, acoustic, haptic, motor and / or olfactory perceptions can constitute a landmark or be otherwise useful for navigation (see e.g. Downs & Stea, 1982, p.108). Thus laboratory settings mostly do not represent the richness of the real world.

1.9.2.2 Field studies

It's the other way round for field research in real settings outside. On the one hand, it is very difficult and sometimes even impossible to provide all the advantages mentioned above for laboratory research. On the other hand, investigations in a natural setting and possibly with an ordinary, naturally occurring context provide meaningful and thereby externally valid data. External validity with regard to the research situation, i.e. the possibility to generalize these results to similar natural settings and contexts, is the main advantage of field studies compared with laboratory research. If we are interested in learning about naturally occurring human spatial behavior, we have to provide a research situation similar to everyday situations in a natural environment so that subjects can use familiar strategies and show usual behavior.

Otherwise, most subjects are successful at using all aids available in a particular situation to perform well, but this does not mean that they usually use these strategies and aids in everyday life.

Thereto Steck & Mallot (1999) showed that results gained in laboratory studies providing only selected spatial cues cannot be transferred easily. They instructed subjects to use only local landmarks in a VR featuring both local and global landmarks. Nevertheless, whenever the local landmarks were not visible, subjects easily switched to the use of global landmarks.

The combination experimental field study which applies to my experiments in the real setting unites high internal and external validity.

1.9.3 Virtual realities

Both extension and improvement of laboratory experiments and new possibilities for reliable data recording in the field reduce the differences between laboratory and field research.

New technologies and software tools as well as the increasing power of computers paved the way to combine the advantages of laboratory and field research. Virtual realities are three-dimensional, egocentric computer generations of an artificial or really existing territory. These technologically created, immersive, and interactive spaces are designed to invoke the sensory systems into perceiving a desired condition or situation. The scene to be displayed is calculated for a virtual camera view, from a specific point and with a specific field of view (size depends on the equipment's possibilities).

Especially with regard to navigation research, it is a big advantage that virtual reality technology provides multifaceted possibilities to design and change virtual

environments and also to intervene into the perception-action sequence. That way, the amount and kind of spatial information available can be controlled and we can draw conclusions on its effects on orientation and navigation. Moreover, the effects of the discrete sensorial modalities can be investigated independently.
Virtual realities offer the chance to combine the richness of the real world with the reliability of experiments in the laboratory.
Thereby, an important factor is **immersion**, that is the impression of having left the real world and being present in the virtual environment.

There are different types of this usually interactive, real-time man-machine interface. The degree of immersion varies depending mainly on technical possibilities. **Desktop systems** feature a small degree of immersion whereas a vision dome is located at the other end of the immersion continuum, i.e. the user becomes fully immersed in this artificial, three-dimensional world. Desktop systems represent virtual realities on a computer screen, they are cheaper and easier to obtain, but lack immersion.

Immersive systems like CAVE, head-mounted display, and vision dome provide a larger field of view. Here, "the user is immersed in or surrounded by the virtual environment" (www.5dt.com).

The **CAVE** is a room-sized visualization system where the user is surrounded by projection screens. CAVE combines high-resolution stereoscopic projection technology and 3-D computer graphics to create the illusion of complete sense of presence in a virtual environment. It was the first virtual reality technology to allow multiple users to immerse themselves fully in the same virtual environment at the same time (Fakespace Systems Inc.).

A **Head Mounted Display** (HMD) consists of two miniature displays mounted in front of the user's eyes with a headmount and two headphones for acoustical input. Special optics enable the user to view the miniature screens. As the user looks around, the position and orientation of the user's head is tracked by means of a head tracker and continuously relayed to the host computer. The computer calculates the appropriate view (virtual camera view) and displays this view on the miniature displays (Fifth Dimension Technologies).

For my experiments, I used a **vision dome** providing a 360° projection and a 180° field of view by its tilted hemispherical screen. The observer is positioned in the middle of the Vision Dome and has a visual image of the virtual reality of 180° in all directions. Thereby the observer loses the normal depth cues, such as edges, and perceives 3D objects beyond the surface of the screen. That way, he/she becomes completely immersed in the virtual world. Another advantage of the vision dome is that observers can move their heads freely and do not need to wear restrictive goggles (Elumens Corporation). For further description of our vision dome and the virtual environment depicted, see Chapter 1.10.2.
In this thesis, the term VR refers to the vision dome as an 'immersive virtual reality' (unless otherwise indicated).

1.9.4 Previous navigation research in R and VR

Previous research has shown that the acquisition of spatial knowledge in, as well as the transfer between both environments R and VR is principally possible and that the essential spatial information most people use in real environments is included in virtual environments, as well (e.g. Witmer, Bailey & Knerr, 1996; Waller, Hunt & Knapp, 1998). However, it depends heavily on the concrete features of the virtual reality used and on the performance definition and its measurement methods (for an overview see Figures 1-4).
Allen & Singer (1997) compared virtual realities varying with regard to interactivity (high vs. low), landmark characteristics (distinctive vs. non-distinctive, and proximal vs. distal), and time of exposure to the terrain. The distinctive landmark version consists of an abstract terrain featuring distinctive elements, whereas an army training site containing relatively flat landmarks represents the non-distinctive terrain. Interactivity influenced results only in the version with the non-distinctive landmarks: Surprisingly, low interactivity lead to better distance estimations. The authors trace this result to the increased task demands in the high interactivity condition.
Landmark proximity influenced results only in the distinctive landmark version: First, the direction of proximal landmarks was estimated more accurately. Generally, visual

acquisition of proximal landmarks is easier due to the larger size perceived. However, in the non-distinctive landmarks version landmarks are relatively flatter which makes it more difficult to acquire these landmarks visually. In addition, these non-distinctive landmarks are more easily affected by the low HMD resolution. Finally, the abstract terrain of the non-distinctive version does not provide further land features as visual cues which could help to acquire structural spatial knowledge. Therefore, direction estimation accuracy of landmarks may be generally lower in the non-distinctive version.

Second, the distance towards proximal landmarks was overestimated, whereas the distance towards distant landmarks was underestimated in the distinctive landmark version. The authors assume that a blending effect of the HMD (pushing proximal landmarks outwards and pulling distal landmarks inwards) accounts for this result.

Furthermore, increasing exposure enhanced directional accuracy of landmark indication, but not distance estimation accuracy. I suppose that direction estimation tasks require more survey knowledge of the area (which is developed with further exposure), whereas distance relations between two locations can be learned faster.

To sum up, Allen & Singer (1997) found quite different performance levels in slightly different kinds of virtual environments. Consequently, results obtained in one kind of virtual reality cannot be generalized easily to virtual realities in principle. Instead, the single impact factors and their combination have to be considered.

There are many other relevant features of virtual realities, like visual flowfield (Psotka, Lewis, & King, 1998) and movement parameters (Ruddle, Payne & Jones, 1998; Chance, Gaunet, Beall & Loomis, 1998). We can distinguish **active** (direct exploration of the environment, e.g. as a pedestrian, biker or driver) and **passive interaction** (listening to somebody's report about the environment, watching it in a movie or moving in it as a passenger).

Furthermore, we can distinguish investigations inside a (virtual) building and outside.

Ruddle, Payne & Jones (1997) experimented with large-scale buildings. Although the virtual reality system they used (desk-top virtual environment) is not known for a high level of immersion, their subjects overcame initial orientation problems and showed good performance (here measured via direction estimation, distance estimation, and route-finding), even comparable to results obtained in real buildings.

Investigations outside of buildings were done e.g. by Péruch, Belingard & Thinus-Blanc (2000) who evaluated “the effects of the amount and quality of information on the transfer of a spatial representation” (Péruch et al., 2000, p.257) from a virtual to the real setting. They used a desktop VR to represent three virtual versions of the campus with a varying amount of details. The poor version included only a subset of the campus buildings, the medium version included some buildings and the main roads, and the rich version included in addition to the medium version further details like vegetation. In the training phase, subjects freely explored the virtual environment, either in the poor, the medium or the rich condition. In the test phase which took place in the real environment, subjects were asked “to indicate the direction, the traveled distance (…), and the direct distance of the other locations” (Péruch et al., 2000, p.258) from six different locations. Direct distance estimation was about the same in all three conditions, but the qualitative differences between poor and medium/rich conditions had a significant effect on direction and traveled distance estimation performance: subjects performed better in the medium and rich condition; There were no significant differences between medium and rich conditions which decreases the importance of the quantity of information available. Supposedly, the addition of roads in the medium and rich version providing a structure and location linking system, improves subjects’ spatial representations. Nevertheless, performance in the poor condition shows that even in very schematic virtual environments, subjects are able to transfer spatial knowledge from VR to R.
Moreover, the results obtained by Allen & Singer (1997) make clear that in order to judge on the general effects of virtual realities, we have to take into consideration various performance measures. Their above described experiment as well as the following experiment by Gale, Golledge, Pellegrino & Doherty (1990) shows that some measurement methods are affected by changes in environment whereas others are not.
They had children (ages 9-12) learn routes either by walking on the real route (in the field) or by watching a video tape and thereafter tested scene recognition, sketch mapping, and navigation. The choice of environment did not have a significant effect

on recognition performance, but on sketch mapping and navigation. The video group remembered a greater variety of features, however, they needed five video sessions in order to approximate the navigation performance that the other group showed after one field session. Thus watching the video enabled the children to remember or recognize single scenes or features, but complicated the acquisition of procedural and survey knowledge.

Thorndyke & Hayes-Roth (1982), who had adult subjects, got similar results. They used two different methods of spatial learning and could show that each method leads to a certain kind of spatial knowledge, resulting in high performances on complying measures and lower performance on others. Learning by navigating in the terrain fostered the acquaintance of procedural knowledge, whereas map learning fostered the development of survey knowledge. Likewise, Presson & Hazelrigg (1984) reveal differing spatial representations for different ways of spatial training. Navigation learning lead to a very flexible spatial representation, whereas map learning lead to a spatial representation featuring a specific orientation.

Sellen (1998) compared direction estimations in a familiar territory. Subjects had to make estimations at various positions in the real or virtual city of Tübingen, using their cognitive map of the city, which they had developed during several years of residence. Results show only minor deviations between both groups, which implies that in this case spatial knowledge acquired in the real setting can be adequately transferred to virtual reality.

But how about the transfer from virtual realities to reality? This is one of the questions investigated in the first experiment.

I noticed that most authors used either real or virtual environments. A small number employed both, but most of them had independent groups therefore lacking the possibility for intraindividual comparison. Actually, little research has been done with regard to the transfer between real and virtual environments. However, this is the prerequisite for the application of virtual realities as a training device for real settings.

So far, there were only very few authors comparing human spatial behavior in a real and a virtual version of the same environment. In addition to Sellen (1998), Péruch, Belingard & Thinus-Blanc (2000) compared the accuracy of spatial representations acquired in R and VR. They had subjects freely explore either the real (real group) or the virtual version (virtual group) of the campus. Then, both groups were tested (direction and distance estimations) first in R, second in VR. Unfortunately, this sequence was not permuted. Comparing both training groups, the real group performed better in both test environments. These performance differences were statistically significant only in the virtual test environment: the real group showed similar performance in both test environments (successful transfer from R to VR again) whereas the virtual group performed better in R (successful transfer from VR to R) and worse in the virtual test environment (these results are confounded with the sequence of test environments, i.e. as the real test followed the virtual test, the virtual test provided additional training possibilities).

1.9.5 Spatial knowledge acquisition

We either take subjects who already know the experimental environment or we enable them to acquire relevant spatial knowledge during a training phase.

An example for the use of knowledgeable subjects is the study of Sellen (1998). She took subjects who had been living in the town of Tübingen for a minimum number of years and asked them to estimate directions between various locations. The advantage is that she could investigate spatial knowledge acquired gradually in a natural context and environment. However, it is difficult to make interindividual comparisons as the amount of previous knowledge cannot be judged from simple measures (e.g. years of residence) and may differ enormously.

Therefore, the prevailing method of spatial cognition experiments is to first train subjects and to test afterwards. Thereby, subjects get the same chances to acquire relevant spatial knowledge. In VR, it is no problem to create an artificial environment that subjects do not know before. In R however, the experimenter has to carefully select an environment that is completely unfamiliar to subjects, but still close enough to allow for reasonable transportation durations from the subjects' homes to the experimental site.

Figure 2 gives an overview of the topics to be considered when deciding on spatial acquisition method and experimental environment, namely interaction with environment and environment's characteristics, exposure to environment, and training procedure. These variables can be distinguished in real and virtual environment.

To start with **interaction**, active interaction (e.g. when moving independently, controlling the speed, etc.) is usually superior to passive interaction (e.g. being a passenger), because it provides a higher level of control and adaptability to the subject and is therefore more motivating than passive, controlled methods. Péruch, Vercher & Gauthier (1995), Allen & Singer (1997), Wilson, Foreman, Gillett & Stanton (1997) varied the level of activity in their studies, whereas Downs & Stea (1982, p.110) provide some theory.

The next variable, **movement parameters**, is related to activity. Unless subjects received special training, it is easier for them to move in a familiar way, namely rather on foot than by using a computer mouse. In VR however, it is still very difficult to install natural movement opportunities. Right now, we are the first ones to install a treadmill and the necessary device and software providing real walking in VR, i.e. the possibility to walk and to turn on the treadmill which triggers the image in the vision dome. For studies about movement parameters see Ruddle, Payne & Jones (1998) and Chance, Gaunet, Beall & Loomis (1998).

Immersiveness is enhanced by a large flowfield, high independence of head movements, real time display, and high resolution.

In reality, our visual field encompasses 160°, whereas in VR, the **flowfield** varies according to the possibilities of the equipment. A flowfield of at least 170° should be aspired in order to enhance immersiveness. Research about this topic was done by Psotka, Lewis & King (1998).

A screen encompassing 180° allows for **head movements** up to 10° in each direction without missing part of the visual image. A desktop VR cannot provide an image filling the complete visual field, whereas a HMD always provides the complete image independent of head movements.

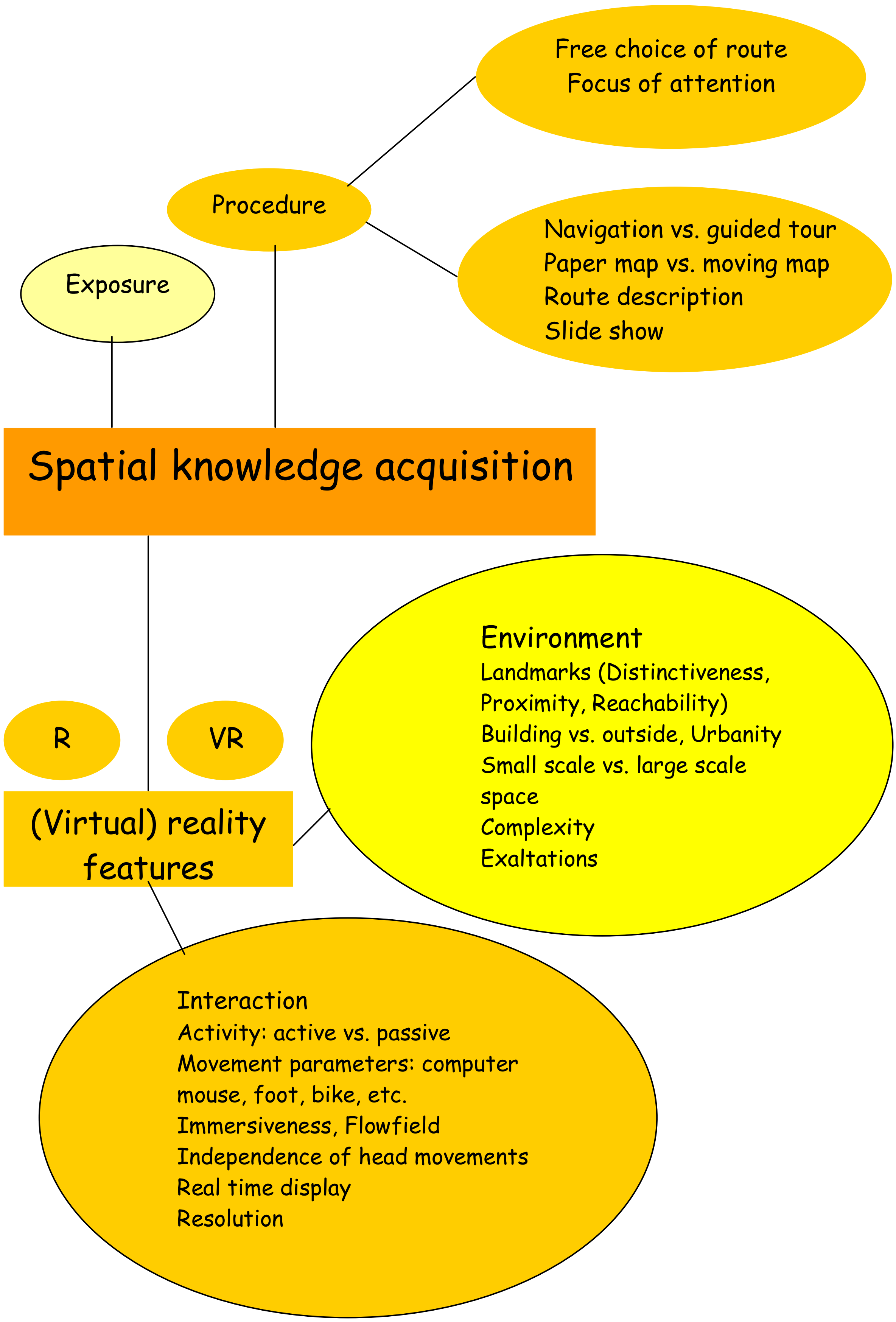

Figure 2: Relevant aspects of spatial knowledge acquisition

Table 4 compares the three prevailing types of VR with regard to the above described factors interaction and immersiveness.

1. Column: factor categories influencing spatial knowledge acquisition
2. Column: positive factors, i.e. the higher the degree of activity, flowfield, etc., the smaller the difference between training conditions in real and virtual environments

3.–5. Column: Three main types of virtual environments and their approximate extent of realization of the factor noted in the second column;

+ high degree, very good

o medium level

- low degree, bad or no realization

For example, the flowfield is quite limited at desktop virtual realities, mediocre at head mounted displays (HMD), and complete at screens like our vision dome.

Impact factors		**Desktop**	**HMD**	**Dome**
Interaction	Activity	-	+	o
Immersiveness	general	-	+	+
	Flowfield	-	+	+
	Independence of head movements	-	+	o
	Resolution	+	-	+

Table 4: Comparison of different virtual reality interfaces with regard to interaction and immersiveness

Both in R and VR, there are different kinds of **environments** that can be used for spatial cognition research and that make a difference with regard to navigation and orientation processes. I distinguish navigation inside of buildings (Ruddle, Payne & Jones, 1998; Poucet, 1993) and outside, small scale and large scale space, and urban and rural areas. Most research I know was done in urban areas, probably because urban areas encompass a large number of navigation relevant features (e.g. landmarks, nodes, and edges) within a small territory and represent the usual navigation environment of experimental subjects.

In addition to the different kinds of environments, the specific features within the environment, e.g. the number and quality of landmarks (Allen & Singer, 1997, further described in Chapter 1.9.4; Ruddle, Payne & Jones, 1998) and the complexity of the environment play an important role. As many people use landmarks for orientation, an adequate number of high quality landmarks as well as low complexity of an environment are likely to facilitate orientation and navigation. Steck, Mochnatzki & Mallot (2003) investigated the role of geographic slant in navigation tasks and found that adding geographical slant improves navigation performance.

However, the possibility to generalize the results, i.e. the representativeness of the environment and thereby the external validity of the study, are more important than pure facilitation. So, if we want to generalize our results to a certain kind of environment, we have to choose an experimental terrain that is representative both with regard to the kind of environment and its features and complexity. In other words, the results of a study are limited to the characteristics of the experimental environment.

Of course, the **exposure** to the environment in question is important (Allen & Singer, 1997). However, the rule is not as simple as "the more exposure, the better the resulting spatial knowledge". As described above, we have to consider interaction, immersiveness, and environmental characteristics, but also the training **procedure**. **Free choice of route** enables subjects to make active experiences with the environment, but does not guarantee constant training conditions for all subjects.

The training context and the derived expectancies influence the subject's **focus of attention**. Often subjects do not know about the actual aim of the experiment in which they are taking part. Then, the cover story has an impact on the subject's selective perception and his/her effort to notice and remember certain aspects. For example, a subject knowing that the next task is to describe the currently walked route may focus more on turnings and directions than a subject expecting to evaluate the surrounding landscape design.

There are various **ways of training** subjects in a new environment. The subject's navigation can be based on various aids. **Exploration** provides only the edges of the terrain to be explored and enables the subject to choose his/her way independently. Otherwise, the experimenter can walk around with the subject or **guide** the subject on a certain route (at my first and second experiment). Additionally, the experimenter can give standardized information about the route, appearing landmarks, or other features. Other possibilities are to have the subject navigate on a certain route with aids like a standardized **route description** (see my second experiment) or map, or to ask the subject to find certain goals (Popp, 2000). Instead of directly moving in the environment, subjects can also learn from a map, a route description, a slide show or other information presented to them.

1.9.6 Measurement of spatial knowledge

Methods provided for spatial knowledge acquisition and methods used to inquire spatial knowledge have to match. Especially the dominant type of spatial knowledge (landmark, route, or survey knowledge) has to be considered. For example, if subjects train particularly landmark knowledge, the following performance measurement should focus on landmarks as well and therefore use the related methods. Of course, we can also check if subjects manage to develop comprehensive survey knowledge after learning a sequence of landmarks. However, if overextending tasks prevail, most subjects might get frustrated and consequently decrease in motivation. Research done by Thorndyke & Hayes-Roth (1982) confirms high performances on complying measures and lower performance on others.

There are three dominant types of spatial knowledge, landmark, route, and survey knowledge and adequate measurement methods focusing on these different types of knowledge (see Figure 3).

Landmark knowledge can be tested e.g. by object recognition tasks (presenting the cues e.g. verbally or on photos) and free recall tasks.

Questions for the continuation of the route at decision points, e.g. junctions, and questions for a certain distance walked on the route test **route knowledge**. Research on landmark and route knowledge was done by Gale et al. (1990) and Goldin & Thorndike (1982).

Survey knowledge is tested e.g. by global direction or beeline distance estimations. Subjects have to indicate relations (direction or distance) between two locations that are not visible from each other. Furthermore, the direct connection between these locations should not be part of the training phase, but it should be possible to infer these beeline connections from the trained knowledge. If subjects are able to do so, they have developed a cognitive map of the area. An example for a direction estimation based study is Sellen (1998).

Navigation tasks, like search for routes and/or specific goals, test the utility of spatial knowledge to find a route and to retrieve one or more goals. In order to navigate successfully, subjects must have developed route or additionally survey knowledge. As navigation is an everyday situation, navigation tasks are representative for subjects' navigation in everyday life. Navigation performance can be measured by various variables. Goal retrieval within a certain time limit distinguishes two groups, successful and nonsuccessful navigators. Thereby, it is not important how the subject reached the goal, i.e. the route taken and the number of turn backs are not decisive as long as the goal is reached within the scheduled time limit. Of course, the researcher has to justify his/her determined time limit. Given that the limit is set for 20 minutes, this method does not distinguish between a subject who found the goal right away, e.g. after 8 minutes, and another subject who found the goal after 19 minutes including various turn backs. Therefore, the time needed for navigation is more exact. The route taken may be an indicator of a cognitive map if there is a possible shortcut between start and goal that is not part of the training route. A subject taking this shortcut purposefully has developed a cognitive map of the area. However, it is difficult to determine quality factors for route evaluation. A high number of turn backs indicates a subject's uncertainty. However, a low number of turn backs does not necessarily mean that the subject is well oriented. Some subjects embark on the strategy to reach familiar objects or views to reorient by trying ways by chance without turning back. Especially in the latter case, coincidence may influence a subject's navigation success. The smaller the number of decision points and the number of possible ways, the higher the probability to choose the correct way by chance and thus the higher the effect of coincidences on navigation success.

Cognitive representations can be investigated by verbal and non-verbal methods. These methods prevail an interesting insight into people's spatial knowledge and cognitive maps. However, both the inquiry method and previous knowledge and concepts influence the results. In addition, it is difficult to judge on the quality of a route description or sketch map.

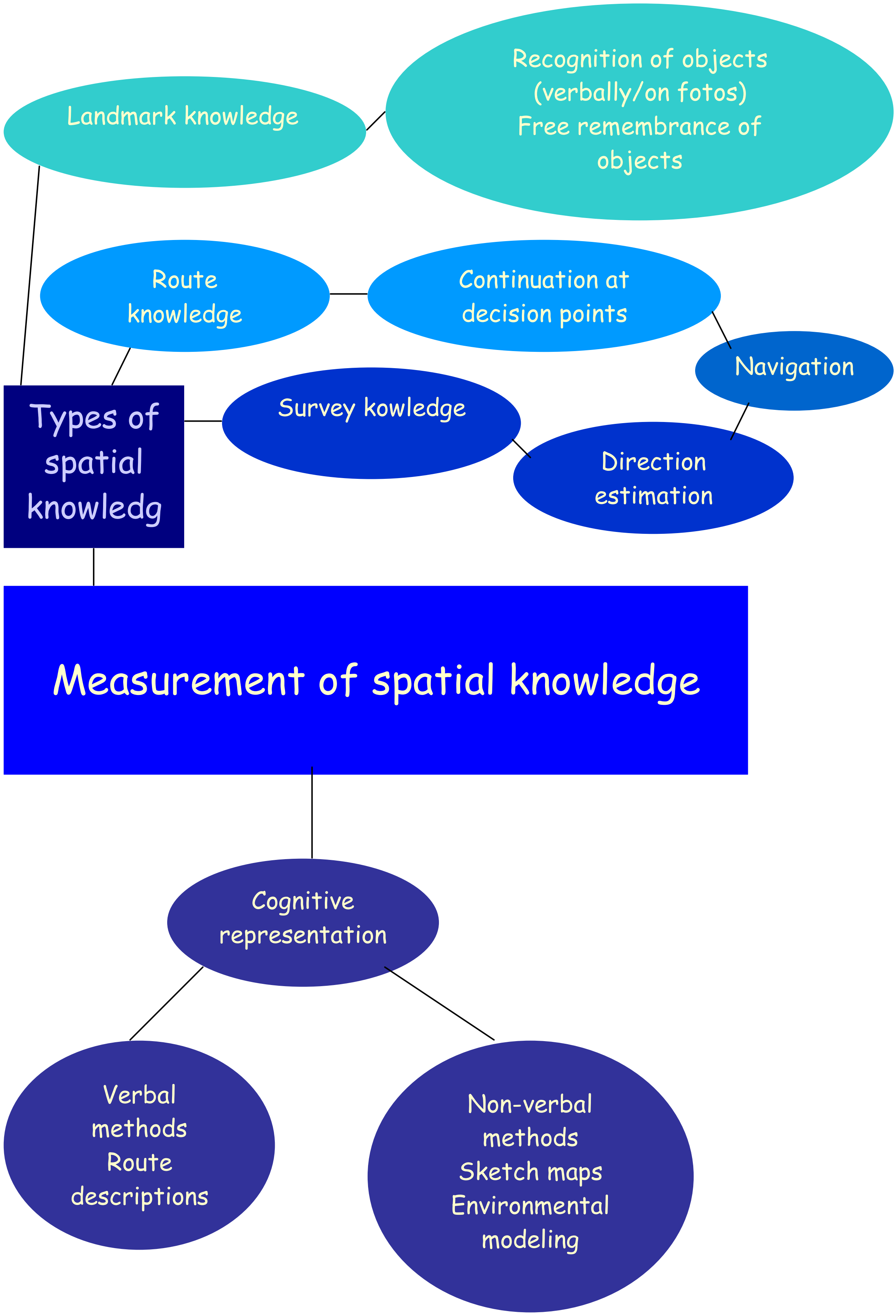

Figure 3: Measurement methods for spatial knowledge according to the type of spatial knowledge

In order to employ verbal methods, subjects should have developed at least some route knowledge. Examples are route descriptions, thinking aloud, and navigation strategies. All these methods are employed in my experiments and are further described in the according chapters.

When employing non-verbal methods, subjects should have developed at least some route or better survey knowledge. Possible inquiry methods are drawings (Gale et al., 1990; Wilson, Foreman & Tlauka, 1997) and environmental modeling (Downs & Stea, 1982, p.296).

Drawings allow for indication of directions and distances saved in a subject's spatial representation. However, the resulting sketch maps depend also on the subject's drawing abilities and the kind of maps, he/she used to deal with.

The other method that Stea and Taphanel (1974) called environmental modeling does not feature these disadvantages. Small objects represent buildings, streets, nodes, etc. and have to be arranged in order to recreate the area in question. Nevertheless, if these small objects represent specific recognizable objects, this is no free recall, but an easier recognition task, and the specific objects' meaning may influence results.

So far, there is only a small number of navigation studies investigating orientation or **navigation strategies** (Schönebeck, Thanhäuser & Debus, 2001; Pazzaglia & De Beni, 2001; Kearns, Warren, Duchon & Tarr, 2001). Most of these laboratory research studies focus on one or two specific abilities and strategies. To my mind, it does not make sense to design experiments allowing for one or two strategies only. In everyday life, people are usually good at finding new strategies and compensating for weaknesses. Therefore, experiments providing only a very limited number of strategy possibilities, cannot measure ordinary behavior. As I am interested in subjects' ordinary spatial behavior, my experiments are designed in order to provide a large number of cues similar to usual urban environments. These cues enable subjects to use similar navigation strategies than in everyday life and do not artificially limit the variety of possible strategies.

There are several possibilities to classify and group navigation strategies (e.g. according to landmark reference or according to time, position, or frequency of usage). I decided to investigate and substantiate the model proposed by Siegel &

White (1975) which I described and discussed in Chapter 2.4. I will relate concrete navigation strategies to the stages of spatial knowledge acquisition (landmark, route, and survey knowledge). This relation between strategies and stages indicates what stage is the prerequisite for the use of the related strategies. Thereby, the stage is regarded as a necessary, but not as a sufficient prerequisite to the use of higher level navigation strategies. This means that somebody disposing of a survey of the area can use navigation strategies based on landmark, route, and survey knowledge, whereas someone else who has only landmark knowledge can use landmark based strategies only. This way, the investigation of navigation strategies reveals both information about common navigation strategies and their success, and about (dominance) stages of spatial knowledge.

1.9.7 Subjects' characteristics

Personal characteristics (see Figure 4) have a moderating effect on both spatial knowledge acquisition and performance.

Of course correct **previous knowledge** about the environment in question usually facilitates the acquisition of added knowledge which can be directly integrated into the existing cognitive map. There are contact points for new and existing knowledge.

On the one hand, when orientating and navigating in a terrain, people often do have some knowledge about this terrain. This knowledge may result from earlier visits, but also from maps and descriptions. Furthermore, in everyday life, spatial knowledge often develops gradually. Therefore, taking subjects who have been living in the environment to be tested (e.g. Sellen, 1998), enhances the external validity of the spatial knowledge acquisition situation and reduces necessary time and costs, because the training phase can be omitted.

On the other hand, if subjects already do have some spatial knowledge at the time of beginning the experiment, the experimenter cannot control the kind and amount of training each subject had previously got. Inquiries in regards to the number of years and months living there are not a sufficient indicator for the quantity and quality of spatial knowledge gained. For example, it makes a big difference if someone frequently moves around in different parts of the town and if he/she usually moves by bike or car or takes the subway. Driving the car or going by bike provide better training possibilities than subway rides. Therefore, the amount of navigation

experiences also depends on the means of transportation usually used. Intentionally taking groups that feature different kinds or levels of spatial knowledge is another possibility allowing for quasi-experimental designs.
This lack of control that reduces internal validity especially for experiments comparing different groups of subjects, is an important reason why most researchers decide to take subjects who don't know the area and provide them with a standardized training. When employing virtual realities that do not represent a really existing environment, the training is necessary because subjects do usually not have any spatial knowledge about the area. This facilitates the control of equal chances, but lacks the possibility to compare spatial behavior in the real and in the virtual version of the same environment.
Investigating in real environments, it is much more difficult to provide an area that subjects do not know at all, but which is still close enough to their home, so that there are limited transportation time and costs. Both experiments described in this work were effected in a terrain at the outskirts of Munich that is closed to the public.
Practice in task related fields, here experiences related to moving in VR and navigating in unknown environments, enhances task performance. This basic rule applies to spatial behavior as well.

Experiences in VR may be gained by playing relevant computer games, like ego-shooters, strategy games including orientation and navigation tasks, or a simulation program. Subjects without VR experience, have to use a larger amount of their attention in order to get used to moving in and perceiving the virtual world. On the other hand, it is also possible that 'VR-experts' rather compare the experimental VR with known VRs and focus on technical features which also reduces attention towards spatial features.
Orientation and **navigation experiences** are part of our everyday life. Most of the time, people navigate on the same routes from home to work, to the supermarket, to the fitness center or to a friend's house. Nevertheless, navigation frequency in barely known environments, as it is the case in most navigation experiments, varies heavily among people. Typical navigation situations in unknown environments occur e.g. on the job when sales assistants or craftsmen visit new clients or on vacation, when individual travelers search for sights or hotels in a new place. People that are

accustomed to orientate and navigate by themselves, like the sales assistant or the individual traveler, have collected more experience and practice than people who spend all day working in the same office and follow a guide when going on vacation. That's why I decided to ask subjects for relevant experiences on their job and in their spare time (hobbies).

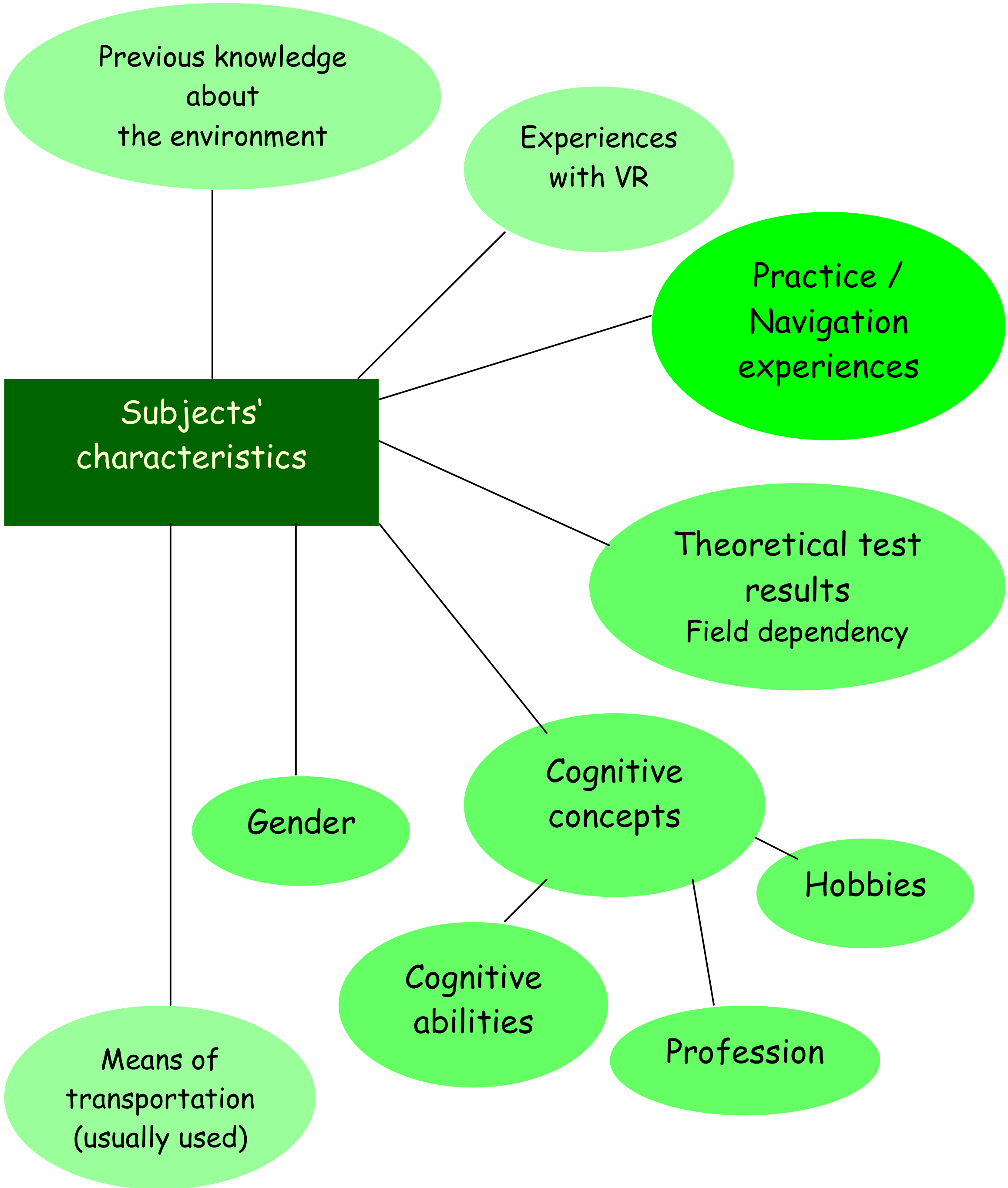

Figure 4: Subjects' characteristics influencing spatial knowledge acquisition and spatial performance

The perception style, more precisely **field dependence**, also seems to be related to navigation performance. Field independent people are likely to perform well on practical navigation tasks. Field dependence is investigated by a paper-based test, the Embedded Figures Test (Witkin, Oltman, Raskin & Karp, 1971), providing moderate correlations with practical navigation performance. The test is further described in Chapter 2.1.9.

Gender seems to have a larger impact on spatial cognition tests than on navigation behavior. In spatial cognition tests, men proved to achieve better results than women (Quaiser-Pohl, 1998). However, there are no sex differences with regard to orientation and navigation behavior.

As described in Chapter 1.2, the spatial knowledge acquisition process is an interaction between bottom-up and top-down processes, i.e. actual spatial perceptions interact with existing knowledge, concepts and expectations. Cultural and personal **cognitive concepts** e.g. what a village looks like (there is a market place and a church in the center, etc.) or how streets are arranged, have an impact on actual perception and expectations.

A perceptional focus on certain elements or the tendency to define perceived objects in a certain way, may also result from one's **profession** and hobbies. For example, a gardener may focus on plants and distinguish very specific kinds, whereas somebody else may just notice a tree or bush or "something green". Likewise, equivocal objects may be named according to the observer's concepts, e.g. a hobby mountaineer may name a hut an alpine hut.

Cognitive abilities influence the spatial knowledge acquisition process via remembrance and/or abilities to abstract.

1.9.8 Psychological fields of interest in spatial research

According to Linn & Peterson (1986), spatial cognition can be investigated from four different points of view. The experiments presented consider all of them:

- Psychometric: observable spatial behavior, thereby paper-and-pencil tests are used to measure spatial cognition and its factors; in the first experiment, I use the Embedded Figures Test (Witkin, 1971);

- Cognitive: internal processes, particularly problem solving processes; I use a structured version of the thinking aloud method to explore the navigation process;
- Strategic: strategies used to solve spatial problems; I focus on navigation strategies to retrieve a goal;
- Differential: differences between various populations; I test the influence of common sociodemographic variables and hypothesized influencing variables, like previous orientation experiences, on navigation behavior;

1.10 Material and Methods

1.10.1 Reality

The large-scale urban area of our experiments is the campus of our university at Neubiberg, near Munich (see Figure 5).

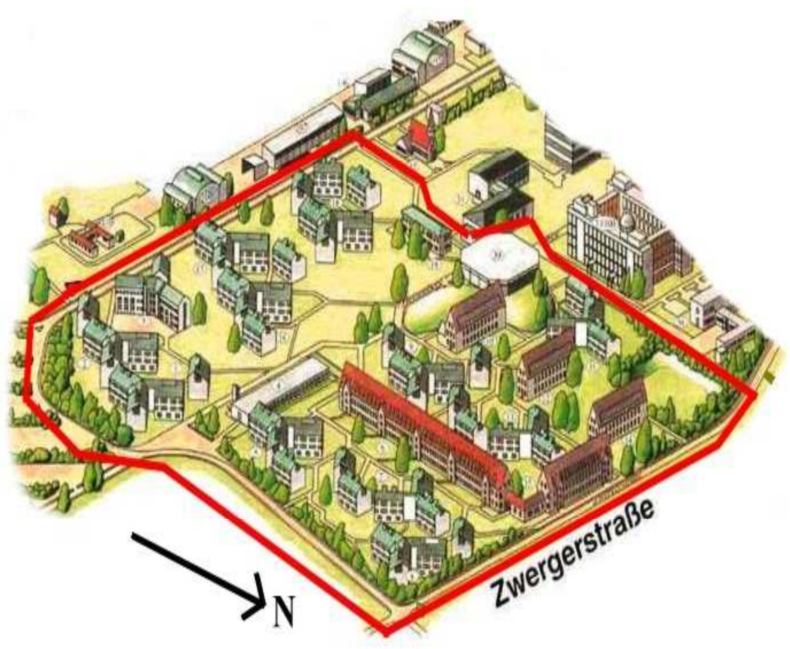

Figure 5: 3D map of the campus of the University of the Armed Forces, Munich

The area is a square of approximately 500m border dimension. Within that area there are more than 50 buildings, some are identical, others are of different size and shape, which are nestled among thousands of trees and bushes. The connecting paths and roads are rather small, meet at oblique intersections and lack names, except for two. All buildings have numbers, but the numbering scheme doesn't follow any logical sequence. Only people who live there know the area, because it is surrounded by dense vegetation and closed to the public. This enables us to do navigational research in an urban area unknown to all of our subjects.

1.10.2 Virtual Reality

The virtual reality 'NeuViberg' was constructed on a SGI Onyx2 Reality Engine with 2 raster managers (SGI: Silicon Graphics Computer Systems, USA). The software was written in 'Performer V2.2', a GUI in C++ based on the SGI graphics language GL. The 'arena' consists of all buildings, relevant objects, vegetation surroundings, sky, atmospheric effects etc. The textures of buildings, vegetation, and other objects are digital pictures from the originals, processed and corrected as needed. The whole scene is projected in the 5m version of the Vision Dome from ELUMENS Corp., USA, providing a 360° projection and a 180° field of view by its tilted hemispherical screen. This is the first and so far the only installation in Europe. Our experimental subjects are positioned in the middle of the Vision Dome and have a visual image of the virtual reality of 180^{o} in all directions. Thereby the observer loses the normal depth cues, such as edges, perceives 3D objects beyond the surface of the screen, and becomes completely immersed into the virtual world. Another advantage of the vision dome is that observers can move their heads freely and do not need to wear restrictive goggles.

As many people had considerable problems moving in the virtual reality with the computer mouse, the experimenter leads the subject through VR, using a computer mouse to control the direction and speed of movement of the visual image within the limits of pedestrian movement possibilities. During the navigational parts of the experiments, the subject indicates the experimenter where he/she wants to go.

The disadvantage is that the passive movement component is enhanced for the subject. However, like this the subject's concentration is not absorbed by steering modalities. In this way, different effects between subjects who can easily move in VR and those who are having a hard time trying to do so can be avoided.

2. First experiment

2.1 Methods

2.1.1 Motivation and Questions

The aim is to investigate human spatial behavior in a real and corresponding virtual environment. Therefore field research featuring a natural setting and an ordinary context is combined with a recent research tool, the virtual reality.

Although the usage of virtual environments as a research or training tool requires the comparability of human spatial behavior in both environments and acceptable transfer performance (between them), we do not really know yet if spatial behavior in R and VR is comparable. Therefore, I decided to investigate this prerequisite. In my experiment, training and test environment are varied in order to reveal their effect on navigation performance and strategies.

Strategies give us an insight into the existence and the structure and details of cognitive maps, whereas performance enables us to assess the cognitive map's utility.

Furthermore, I want to explore whether individual characteristics can predict navigation performance. So far, the effects of gender and age on orientation have been explored several times (Quaiser-Pohl, 1998; Allen, 1981; Allen, 1987). However, other individual characteristics have been neglected. The question raises which other individual characteristics have an effect on navigation performance. And can a few questions to the subject, e.g. asking for his/her navigation practice, predict performance as well as paper based tests? Tests can be an easily applicable and time effective means to predict behavior. However, most spatial cognition tests do not provide good prediction of practical spatial performance in the environment. Previous research has shown low to moderate correlations between results in spatial cognition tests and practical navigation performance (Conrad, 2001). The highest correlation (r=-.794, n=12) was achieved with the Embedded Figures Test (Witkin et al., 1971, described in the next Chapter 2.1.9). This experiment further investigates the prediction accuracy of this paper-and-pencil test.

The resulting questions are related to the navigation process and its differences in R and VR:

- How do people manage to orientate themselves in an urban environment?
- Which details of the route do they remember and use for orientation? What are the characteristics of these details?
- How many different strategies do people use during one navigation?
- What kind of strategies are used in reality and virtual reality?
- What kind of landmarks are used in reality and virtual reality?
- Do successful subjects use strategies that are different from those used by failing subjects?
- Does the frequency of exposure to orientation and navigation situations have an effect on navigation performance?
- Does the amount of field dependence as it results from the Embedded Figures Test (Witkin et al., 1971) correlate with navigation performance?

2.1.2 Dependent and independent variables

The dependent variables are:

- Navigation performance: Success, time, route
- Navigation strategies
- Choice of landmarks
- EFT results

The independent variables are:

- Training environment: reality vs. virtual reality
- Navigation environment: reality vs. virtual reality
- Sequence of navigational environments: first R, then VR or first VR, then R
- Previous navigation experience in different fields (profession, spare time, etc.)
- Sociodemographic variables
- Navigation strategies

Navigation strategies are mainly dependent variables. However, when differentiating subject groups according to the strategies used (e.g. subjects using a certain strategy and subjects not using this strategy) in order to compare these groups, navigation strategies can be independent variables as well.

2.1.3 Subjects

58 adults (29 male, 29 female) participated in the experiment. They responded to an advertisement in the local newspaper and were paid for participation at both sessions. We chose subjects aged 30 to 55 (mean 42 years), i.e. beyond the developmental stage of spatial cognition and before "old age effects" may affect results.

Almost half of the subjects achieved the German intermediate high school certificate ("mittlere Reife"), 35% achieved the senior high school graduation diploma ("Abitur"), and 13% finished the extended elementary school ("Hauptschulabschluß"). After school, most subjects (80%) continued their education in terms of vocational training, 15% completed university studies. At the time of the experiment, most subjects (69%) were employed, 13% were housewives (all women) and another 13% were unemployed (mostly men). In a nutshell, the subjects do form a representative group of the adult population with diverse educational and occupational levels.

To make sure that subjects have the chance to get equal knowledge of the navigation area, I decided to take candidates who have never been to the campus and give them a standardized tour through the campus.

Subjects are divided into four subgroups and are run through the experiment individually. They do not know about the following tasks or the aim of the experiment. After the experiment, an explanation of its goals is given.

2.1.4 Design

The experiment consists of two sessions separated by a pause of one week. This period of time (one week) is long enough to represent delays as they are common in ordinary contexts and short enough to expect subjects to remember spatial information.

At the first session, the training phase, participants train the route on the campus on a guided tour with the experimenter. During the second session, the test phase, each subject has to find the way to the goal on his/her own in both environments.

The experiment's 2x2 design (A*B) features two conditions of training environment (R and VR) and two conditions of test environment sequence (first R, then VR or first VR, then R) that are combined to four different conditions (see Table 5).

Navigation was carried out both in R and in VR by each subject. The sequence was permuted in order to control for learning effects. Groups A and D started navigation in R (followed by VR), whereas groups B and C started navigation in VR (followed by R).

Experimental group	**A** 15 subjects	**B** 13 subjects	**C** 15 subjects	**D** 15 subjects
Training	R	R	VR	VR
Distance estimation	R	R	VR	VR
Test				
Break	1 week	1 week	1 week	1 week
Navigation 1	R	VR	VR	R
Navigation 2	VR	R	R	VR

Table 5: Overview of experimental conditions

2.1.5 Hypothetical assumptions

First, it is assumed that the congruence between training and test environment, i.e. both reality or virtual reality, leads to higher performance.

Second, subjects are more used to navigation in real environments and its different cues. Therefore, the reality training group is expected to be better at navigating in reality than the VR training group at navigating in VR. Both the training and navigation environment are expected to have a significant influence on navigation performance.

As each training and navigation session should have a certain training effect, better performances are expected at the second navigation task.

Contrary to navigation performance, the usage of strategies and landmarks is not expected to depend on the actual navigation environment. It is expected that the same strategies and landmarks are used in both environments. The assumed reason for this is that the visual input, which is relevant for most strategies and therefore dominant for navigation, is almost identical in R and VR. Nevertheless, there is one variable that is expected to be related to strategy usage: navigation success. Although strategy choice precedes success, previous success with a certain strategy encourages subjects to use it again.

To sum up, subjects are expected to use the same strategies in R and VR, but the resulting success may differ in both environments.
Successful navigators are expected to prefer different strategies than unsuccessful navigators. In particular, successful subjects are expected to use the direction strategy more often than subjects failing to find the goal. If someone is able to give a good direction estimation, i.e. one knows in which direction the goal is located without seeing it from one's actual position, then one has an at least rough cognitive map according to my operational definition of cognitive map (see Chapter 1.6.1). Here cognitive map means roughly simplifying the existence of a mental representation of an area containing at least two geographical points and their relations. Thus, if there are subjects using the direction strategy successfully in the new environment, this is an indication for a possible early development of cognitive maps at first contact with the environment. The distances and directions describing these relations may be distorted. Nevertheless, having a cognitive map of an area means having an overview of the territory and therefore being able to navigate well and find shortcuts in an area. For a more detailed discussion of cognitive map definitions see Chapter 1.6.
Another reason for the assumed quality of the direction strategy is its relative independence from concrete route systems, deviations can be compensated at different points.

Regarding personal variables, various orientation and navigation experiences, i.e. the frequent exposure to situations in which someone has to orientate him/herself, are supposed to lead to high navigation performances.
Furthermore, navigation performance is expected to correlate significantly with field dependency as measured by the Embedded Figures Test (Witkin et al., 1971).

2.1.6 Route

Subjects get to know the campus on a training route (see Fig. 7). It starts in front of the commons, goes along different buildings, paths and vegetation, and finishes at a maypole, the goal. The route measures 571m. Both in reality and in virtual reality, it takes about seven minutes to walk from the starting point to the goal. There are a few possibilities to get from the starting point to the goal that cover approximately the same distance.

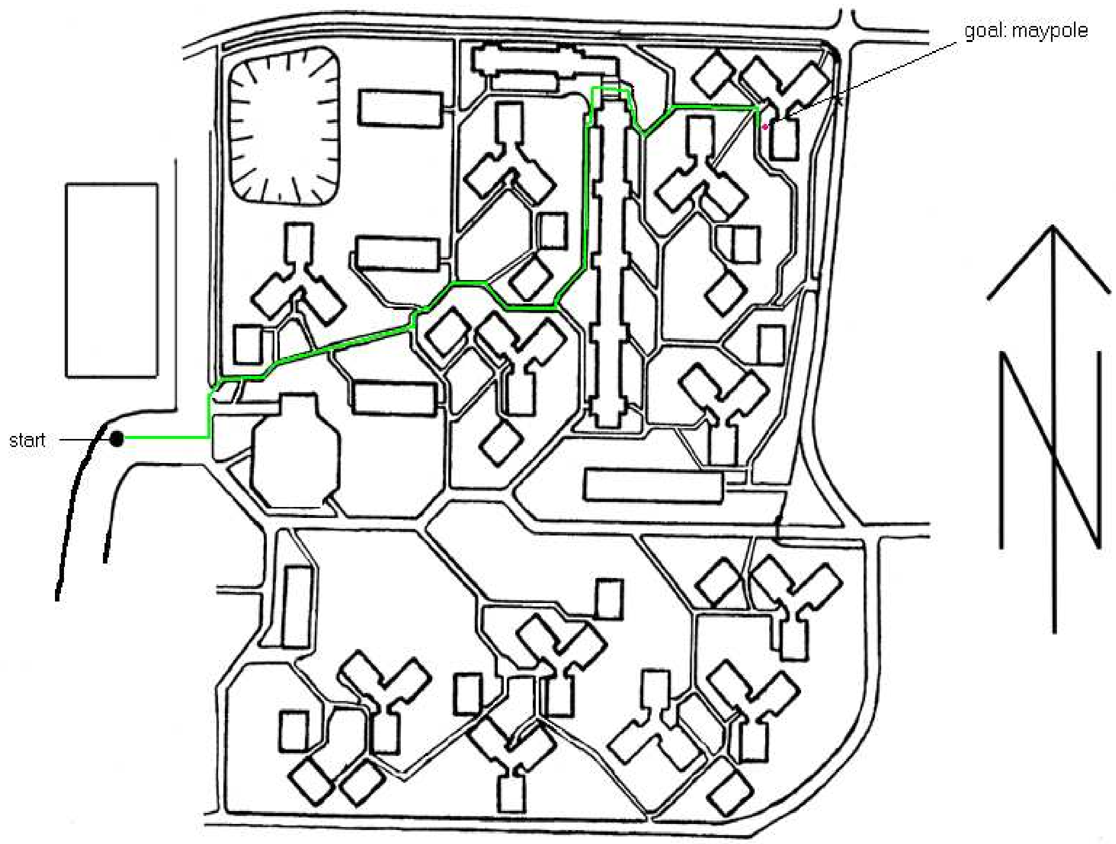

Figure 6: Map of the campus with training route (green)

2.1.7 Procedure

Training phase

To examine for the effects of different training environments (R: reality, VR: virtual reality) on navigation and for the transfer possibilities of spatial knowledge from one environment to the other, two groups (A and B) train the route in reality, the other two groups (C and D) train in virtual reality.

Distance estimation

Immediately after the training phase, subjects have to estimate the length of the trained route by walking the probable distance on the test range, a straight street with either poor or rich environment. Results of this part of the experiment have been presented elsewhere (Popp, Platzer, Eichner & Schade, 2004).

Paper and pencil test

After distance estimation, subjects are administered the Embedded Figures Test (Witkin et al., 1971).

Test phase

After a one week forgetting phase, subjects are transferred to the starting point and asked to go to the maypole, the final point of the route trained during the first session. The experimenter records the duration of the search and marks the route chosen by the subject in a map. Furthermore, subjects are instructed to think aloud and to pronounce their considerations concerning the navigational process.

In addition to thinking aloud during navigation, subjects are interviewed concerning their strategies afterwards.

Finally, all subjects have to fill in a short questionnaire asking for sociodemographic information and for previous navigational training and experiences in various fields.

The first session lasts about one hour, the second session one hour to one hour and a half, depending on the amount of time the subject needs to find the goal.

2.1.8 Data recording

During the training phase, the duration of the training walk was recorded in reality by stopwatch, in virtual reality by the computer log.

During the test phase, we used a variety of data recording methods, some of them completing one another. In virtual reality, data like navigation duration and route chosen were registered by the computer. In reality, the experimenter measured duration with a stopwatch and marked both the subject's route and his/her turn arounds on a map of the terrain. The subject's statements during navigation were registered with a dictaphone.

At the following strategy interview, the experimenter wrote down the subject's answers and inquired further details if necessary.

Sociodemographic information and previous navigational experiences were collected with a short questionnaire filled in by the subject.

Influencing factors like weather conditions, subject's motivation, etc. were noted at both sessions.

2.1.9 Embedded Figures Test (EFT)

The EFT (Witkin et al., 1971) is a paper-and-pencil test investigating the perception style, more precisely field dependence, which proved to be relevant for spatial cognition tasks / performance in earlier research (Conrad, 2001).

In order to solve the problems, subjects have to distinguish simple geometric forms like triangles from their background (a more complex figure), and discern various given shapes. Instructions and test take about 15 minutes.

In the test manual, Witkin et al. (1971) discuss whether the score should be interpreted in terms of performance or rather in terms of perception style.

Field dependent persons perceive the environment rather as a whole, i.e. the parts merge into a cumulative structure whereas field independent persons perceive the entirety and its parts (Witkin et al., 1971). Applied to perception and orientation in an environment, field dependent people may perceive and remember a view from a certain position (e.g. an arrangement of buildings and paths including one or several landmarks), whereas field independent people are able to isolate one landmark from the whole view in order to memorize it for navigational purposes.

2.1.10 Thinking aloud

Most measurement methods for cognitive maps (presented above) are restricted to pieces of information that subjects remember.

I was looking for a method to gain information about the representation that subjects have of an area in the navigational setting at the moment of comparison (internal representation ⇔ real world). In addition, we want to learn about the strategies subjects use to orientate themselves and to retrieve the route and goal.

Subjects are asked to recall their representation like they would probably do it in everyday life and verbalize it. Thus, I can enhance the generalizability of results by providing a more natural verbalization situation. Furthermore, I can avoid memory distortions.

Thinking aloud means neither theorizing about the problem solving process, nor introspection, but pronouncing present thoughts and considerations (Deffner, 1989).

After an explorative pilot study, I noticed that most of the statements made rather correspond to a route description and provide a huge amount of qualitative data with little relevant information (Conrad, 2003). Therefore I decided to structure the original method. I consider the thoughts at decision points to be relevant, i.e. at junctions where subjects have to decide on a way. There the experimenter asked the subject where he/she wants to go and why? After a training unit outside the experimental area most subjects reported their considerations without being asked. Supposing that the problem can be subdivided into consecutive parts like in the present case (see Chapter 1.3: process of keeping the itinerary), high validity and reliability are attributed to the method thinking aloud (Deffner, 1989).

In order to know how our subjects experienced this method, we asked them how difficult it was for them to verbalize the decision process of navigation and if thinking aloud had any effects on their navigation process. For 75% of our subjects, it was easy or very easy to verbalize. With regard to the method's effects, almost 50% of the subjects thought that thinking aloud had no effect on the navigation process. 43% thought that it fostered navigation. The remaining 7% said that thinking aloud affected navigation.

When discussing the results, we should take into account that most methods which enable the researcher to learn about the subjects' cognitive processes beyond its expressions in subjects' behavior or physiological parameters imply asking subjects to verbalize their thoughts. The experiment focuses on the orientation and decision process during navigation.

When navigating with somebody else who asks why you decide to take a certain path, probably because the person is questioning the decision, or when giving a route description, people have to explain their strategies. Nevertheless, many subjects are not accustomed to verbally express their considerations when navigating.

Furthermore, some subjects may be less eloquent than others and some strategies might be more difficult to verbalize (e.g. direction strategy). Likewise, we should take into consideration that by using the method "thinking aloud", we learn what subjects say, but this does not represent exactly what they think.

2.2 Results: Performance

Before starting to explain the results,I would like to say a few general words about the way results are presented in this section.

T-tests results are generally two-sided, unless otherwise indicated.

Regarding correlations, the coefficient of determination, i.e. the shared variance of two correlated variables, is indicated by r^2.

The effect size d considers both the difference between the mean values of the compared groups and the standard deviation of the measured variable. The consideration of the standard deviation in addition to the mean difference helps to evaluate the practical importance of the difference between the two mean values. The same difference may be of high importance in case of a small standard deviation and of low importance in case of a high standard deviation. The effect sizes of the t-test for independent variables can be classified into small, medium and large effects according to Table 6 below (Bortz & Döring, 1995).

effect size classification	small	medium	large
d	0.20	0.50	0.80

Table 6: effect size classification

Navigation performance is measured by two variables: navigation duration and navigation success.

2.2.1 Success definition

We consider the navigation to be successful if the goal of the trained route was retrieved within 20 minutes. To compare, the guided tour takes about 7 minutes. The chosen route is not a criterion for success because it was purposefully not required by the instruction to take the same route. The task was to find the goal. A subject who has developed a cognitive map of the campus may decide to take a different route leading to the goal in about the same amount of time.

Within 20 minutes subjects get the chance to compensate the choice of a wrong path once or twice and turn back if necessary. However, I noticed that most subjects finding the goal after 20 minutes were unable to orientate themselves and finally found the goal rather accidentally. For example, the route does not aim for the goal, but after having tried several paths, the subject unexpectedly passes the goal. The few borderline cases, i.e. navigation duration between 20 and 22 minutes, were considered individually. In those cases I concluded according to route and strategies if the goal was finally found by chance.

2.2.2 Effects of training and navigation environment on navigation performance

Half of the subjects have trained the route in reality (groups A+B), the other half (groups C+D) have trained in virtual reality. I compare navigation performance of both groups in order to learn about the effects of training environment. Furthermore, I compare navigation performance in both environments within one group in order to learn about transfer effects and intraindividual performance differences.

The **training environment** significantly influences success and duration of navigation in reality, but not in VR. Subjects who had trained in reality retrieved the goal in reality significantly more often (t-test: df=56, p=.023, r^2=9%, d=.62) and faster (t-test: df=56, p=.014, r^2=9%, d=.63) than subjects who had trained in virtual reality. 79% of the reality trained subjects found the goal in reality, whereas only 43% of the virtual reality trained subjects did so in virtual reality.

Reality learners were more successful both in reality (79% vs. 50%) and in virtual reality (54% vs. 43%). Like I had presumed, training in reality allows for better performance in reality. Nevertheless, our hypothesis that the congruence between training and test environment leads to higher performance could not be confirmed for both environments.

Navigation environment had a significant effect on navigation performance in case of the reality trained groups (groups A+B, t-test comparing navigation in R and VR with regard to -success: p=.017, df=27, r^2=15%, and -duration: p=.003, df=26, r^2=39%), but not in case of the VR trained groups (C+D). Table 7 shows average navigation duration for both training groups in the real and the virtual environment. standard deviations are quite high;

As can be seen in Figure 7, group A stands out from the other groups as navigation in both environments was very successful. When navigating in reality 87% were successful, when navigating in virtual reality 67% were successful, which is the highest success rate achieved in virtual navigation environment. Taking into account the small number of subjects in one group (in this case 15), I conclude that good (here repeated) training in reality enables most subjects to achieve successful navigation in virtual reality, as well.

	Navigation duration in R		Navigation duration VR	
	$\bar{x}$	σ	$\bar{x}$	σ
Groups A+B (training in R)	12’57’’	7’15’’	17’33’’	8’30’’
Groups C+D (training in VR)	18’33’’	9’33’’	18’46’’	9’14’’

Table 7: Comparison of the two training conditions with regard to navigation duration

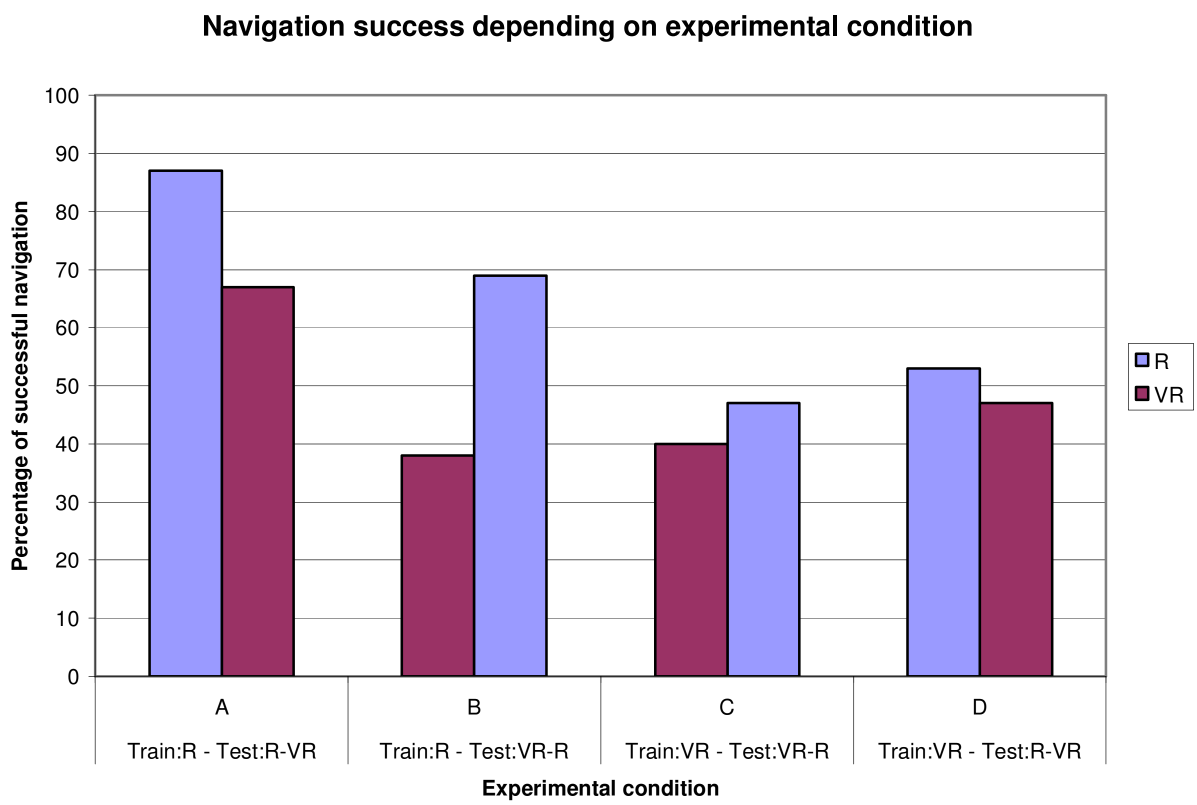

Figure 7: Navigation success depending on experimental condition

However, Figure 7 further shows that in group B only 38% found the goal during their first navigation which took place in virtual reality. Afterwards, at the second navigation in reality, 69% of them were successful which is still less than the corresponding percentage in group A. Thus, group B shows weaker performance than group A at both navigations.

Focusing on the virtual reality training groups (C+D), I noticed that they were also slightly better at navigating in reality regardless of navigation environment sequence. About half of the subjects in these two groups found the goal.

To sum up, navigation in reality seems to be easier for all experimental groups, particularly for those who had trained in reality.

Two multifactorial analysis of variance with repeated measurement were conducted. The dependent variables (inner subject variables) were the durations of first and second navigation. The independent variables (between subject factors) were the four conditions of the experimental design in one case, and the two training environment conditions in the other case. In both analysis, none of the F-values proved significant, i.e. the factors do not contribute significantly to the model. As most independent variables are dichotomous, t-tests are mainly used to test for significant differences.

2.2.3 Sequential effects of navigational environments

Navigation performances in R and VR are related, which is expressed by the respective correlations at both performance measures. Successes at navigation in R and in VR correlate significantly ($r=.297$, $p=.024$) as well as duration of navigation in R and VR ($r=.386$, $p=.003$), i.e. subjects that were successful at the first navigation often retrieved the second goal as well.

Likewise, the sequence of navigation environments did not have a notable impact on results (see Figure 7). The number of subjects who have found the goal did not rise significantly from first to second navigation, which contradicts our learning effect assumptions. Concretely, 35 of 58 subjects (61%) showed consistent performance: They were successful twice (21 subjects) or failed both times (14 subjects).

The remaining 22 subjects (12 women, 10 men) retrieved the goal only in one environment. Only 12 of them improved, among them 8 women and 4 men, implying that the learning effect of first navigation was higher for women. More precise analysis showed that six of these eight women were in group B and C, i.e. the second navigation task took place in their learning environment.

2.2.4 Subject's perception of the reality conditions' difficulty

After the test phase, subjects were asked which kind of environmental conditions they considered to be easier. Those who had trained in reality definitely prefer the real environment. The virtual training group is rather heterogeneous. Almost half of them also prefer reality (14 of 30, i.e. 47%), 30% prefer virtual reality, and for the remaining 23% the environment does not make a difference. The chi-square-test comparing the answer distributions for reality and virtual reality trained subjects is highly significant (df=2, p<.000).

We expected the evaluation of the environment to be related to the subject's behavior in this environment. It resulted no significant coherence between evaluation and success in either environment. Nevertheless, a one way ANOVA analysis reveals significant differences between the evaluation groups concerning navigation duration in virtual reality (df=56, p=.022), but not in reality. Subjects who had trained in virtual reality and who had retrieved the goal there after a short time, considered the virtual environment to be easier.

2.2.5 Embedded Figures Test

2.2.5.1 Scores

The EFT consists of 18 tasks. Every successfully solved problem results in one point, i.e. scores range from 0 (no problem solved) to 18 (worked on all tasks successfully).

Considering the whole sample of 58 subjects, the mean is 9.66 points with a high standard deviation of 5.72. All possible scores exist. There are large inter individual differences, thus the sample shows a broad range of levels. Nevertheless, three groups can be discerned: the low-scoring (0-6 points) field dependent group (22 subjects), the moderately scoring group (7-12 points, 13 subjects) and the high-scoring (13-18 points) field-independent group (23 subjects). Figure 8 shows the bi-modal distribution.

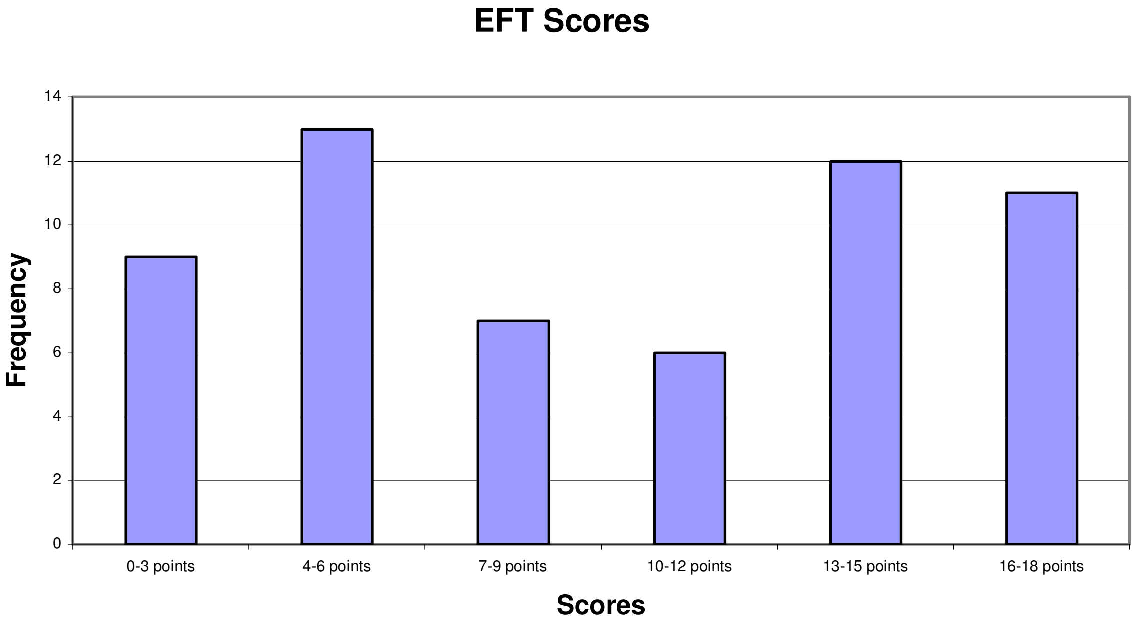

Figure 8: EFT scores (whole sample)

2.2.5.2 Coherence with other variables

EFT scores are related to sociodemographic variables (age, education, previous orientation experiences) as well as to all navigation performance measures (see Table 8). Correlations range between .269 and .481, they are low, but statistically significant and explain 7% to 23% of the variance.

The level of correlation also depends on navigation environment and gender. I found low to medium correlations between EFT and performance measures, which indicate a considerable but not straight coherence of both measures. Navigation in VR (duration and success) correlates higher with EFT than navigation in R.

Furthermore, second navigation duration correlates higher with EFT than first navigation. Additional analysis shows that this coherence (EFT and second navigation duration) applies only to EFT high scorers. With regard to the EFT high scorers (scores 13-18), EFT results correlate significantly ($r=-.421$, $p=.046$, $n=23$) with the duration of the second navigation. However, there are no significant correlations regarding the EFT low scorers (scores 0-6).

In addition, I tested if the EFT high scorers profited more from the first navigation as an additional training unit, i.e. if they improved more from first to second navigation

than EFT low scorers. However, differences of navigation duration at first and second navigation are not significant for neither of the EFT subgroups.
Results show that both practical exercise (orientation experiences) and theoretical knowledge (education) correspond to good performance at EFT.

EFT scores correlate significantly with the following variables:

Variable correlating with EFT score	Correlation	P-value	Relation
Navigation duration in VR	-.437	.001	The higher the test score, the shorter navigation in VR.
Navigation duration in R	-.311	.011	The higher the test score, the shorter navigation in R.
Success in VR	.354	.006	The higher the test score, the more likely success of navigation in VR.
Success in R	.269	.041	The higher the test score, the more likely success of navigation in R.
Duration of first navigation	-.294	.026	The higher the test score, the shorter the first navigation.
Duration of second navigation	-.481	.000	The higher the test score, the shorter the second navigation.
Age	-.277	.035	The higher the test score, the younger the subject,
Previous orientation experiences	.415	.001	The higher the test score, the more orientation experiences.
Education	.419	.001	The higher the test score, the higher the educational level.

Table 8: Correlation between EFT and other variables

2.2.5.3 Gender differences

At the EFT-test, men scored significantly higher than women (t-test, df=56, p=.026, r^2=9%, d=.60) with a high standard deviation (men: σ=5.25, women: σ=5.78). So, on average, men solved significantly more tasks successfully (men: $\bar{x}$=11.31, women: $\bar{x}$=8.0). Concerning perception style, more than half of participating women can be considered rather field dependent whereas the majority of men are rather field independent.

2.2.6 Effects of sociodemographic factors

2.2.6.1 Previous orientation experience

To estimate previous experience with navigation tasks, we asked subjects if and how frequently they have to navigate autonomously in an unknown environment during work and spare time. In a questionnaire, they were asked (answers in brackets)

- if traveling was the main point of their job (27% of subjects)
- how often they had moved to another district or town (average 4.4 times)
- how often they found themselves in the situation to have to navigate autonomously (40% often or very often, 45% occasionally, 13% rarely – this item is called frequency of navigation situations)
- and if they practiced hobbies featuring navigational tasks (this item is called previous navigation experience and consists of several questions, 90% practice relevant hobbies, especially hiking, biking, and individual traveling)

The experience measures, i.e. previous navigation experience and frequency of navigation situations correlate with each other (r=-.435, p=.000). Previous navigation experience also correlates significantly with the number of moves (r=.340, p=.004). Furthermore, previous navigation experience correlates on a low level, but significantly (one-sided) with various measures of performance (see Table 9).

Variable correlating with previous navigation experience	Correlation	P-value	Relation
Success in VR	.286	.015	The more navigation experiences, the more likely success of navigation in VR.
Success at first navigation	-.289	.015	The more navigation experiences, the more likely success of first navigation.
Duration of second navigation	-.237	.037	The more navigation experiences, the shorter the second navigation.
Duration of navigation in R	-.228	.043	The more navigation experiences, the shorter the navigation in R.

Table 9: Correlation between previous navigation experience and various performance measures

Likewise, a similar item “frequency of navigation situations” correlates significantly (one-sided) with different performance measures.

Variable correlating with frequency of navigation situations	Correlation	P-value	Relation
Success in R	.257	.026	The higher the frequency of navigation situations, the more likely success of navigation in R.
Duration of navigation in R	-.244	.032	The higher the frequency of navigation situations, the shorter the navigation in R.
Duration of second navigation	-.292	.013	The higher the frequency of navigation situations, the shorter the second navigation.

Table 10: Correlation between frequency of navigation situations and various performance measures

To sum up, frequent exposure to situations in which someone has to orientate him/ herself and most navigation performances correlate significantly. Thus, we could confirm our assumption that persons with good navigational practice, no matter if it results from profession or spare time activities, show better navigation performances at the experiment.

2.2.6.2 Education

The subject’s educational level correlates on a low level with EFT (r= .419, p= .001) and with subject’s previous orientation experience (r=.383, p= .003), i.e. the higher the educational level, the higher the EFT score and the more orientation experiences.

2.2.6.3 Gender

In both environments, the percentage of successful women is higher than that of men. These differences are more distinct for the virtual training groups (condition C+D, i.e. subjects trained in VR, then navigated in R and VR).

In the real navigation environment, 44% of men compared to 57% of women of groups C+D were successful (difference not significant). In the virtual navigation environment, 25% of virtually trained men found the goal compared to 64% of women (see Figure 9). This difference proves to be significant (t-test, df=28, p=.031, r^2=16%, d=.82).

Regarding men, virtual training environment leads to lower navigation performance, independent of the sequence of navigation environments.

With regard to navigation duration however, there are no significant gender differences.

I noticed that more women took advantage of the congruence between training and test environment. In addition, as described above, more women improved from first to second navigation.

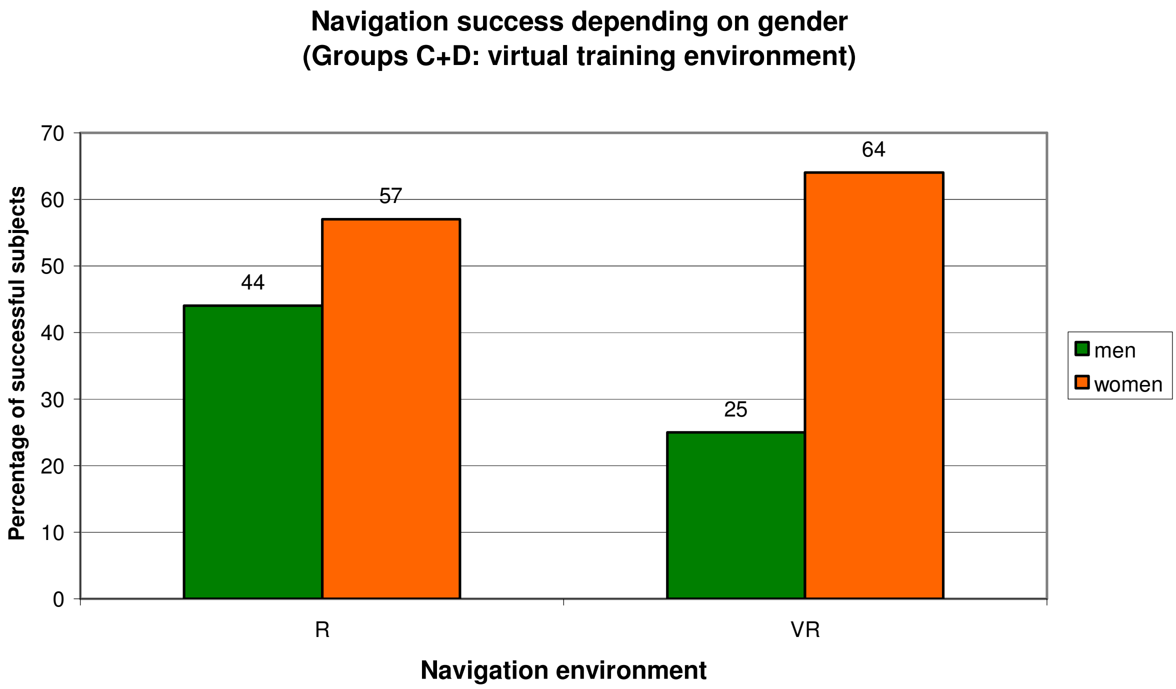

Figure 9: Successful men and women at navigation in VR,
Group C +D (virtually trained)

2.3 Results: Navigation strategies

2.3.1 Investigation method and description of strategies

I wanted to know how people manage to orientate themselves in an urban environment, i.e. what kind of strategies and landmarks they use. Does this navigation process differ from real to virtual environments? What kind of spatial knowledge do people acquire when moving in an unfamiliar environment?
Information about navigation strategies was ascertained by two methods: thinking aloud during navigation and strategy interview afterwards.

For the analysis of the data resulting from the subject's thinking aloud during navigation, I formed categories based on the collected data. Sometimes subjects used several strategies to decide on the continuation of the route at one junction. In that case, I noted all different strategies used. The classification is exhaustive. Generally, I noted which strategies subjects used, but not the frequency of usage. The existing diversity of navigation strategies is the main focus.
Sometimes subjects discontinue using a strategy and start using another one or they use two or more strategies at the same time. This depends on the consensus of these strategies. If the considered strategies lead to a consistent navigation decision, several strategies may be used in order to make one route decision. If the considered strategies disagree, the subject has to decide for one of them, e.g. a subject heading for a specific direction may change direction when recognizing a landmark and nearby path leading to the goal.
Data analysis is based on the interpretation of the subject's verbal statements. At time of classification, I ignored the other subject's data in order not to be influenced by knowledge about performance or sociodemographic data.
Results extracted from both methods were categorized into nine different strategy categories, which will be subsequently described and grouped according to their basis of spatial knowledge.
There are several possibilities to classify and group navigation strategies. I decided to investigate and substantiate the model proposed by Siegel & White (1975) by relating concrete navigation strategies to the stages of spatial knowledge acquisition.
The three types of spatial knowledge, landmark, route and survey knowledge can be differentiated as follows:

Disposing of landmark knowledge means remembering the existence of one or more landmarks, but ignoring the landmarks' location or succession. Knowledge about landmarks can be part of the other two types of spatial knowledge.
If one remembers a landmark and additionally the direction/path to take there, i.e. landmark and direction knowledge are connected, it is called route knowledge. Likewise, route knowledge can be part of survey knowledge.
If someone has a survey of the landmarks' and routes' positions within the area, this person disposes of survey knowledge or, in other words, of a cognitive map of the area.
Although the subjects in my experiment had very little training (they walked only once on the route) before searching for the goal at the navigation session, they used strategies based on all three types of spatial knowledge according to Siegel & White (1975).

2.3.2 Landmark knowledge

<u>Searching for known objects</u>
Attempt to find any known object, i.e. subjects search for any familiar landmark or view in order to reorientate themselves where they are; On the contrary to search for landmarks, they do not look for a specific view or landmark, the only characteristic searched for is familiarity. Usually these are apparently unplanned decisions and subjects take a path without knowing where it leads, hoping that by chance it might bring them back to the route or even closer to the goal.
Examples:
"I can't remember these buildings; I think I haven't been here before. I'll continue walking in order to find again any known features."
"I'm not sure where to go, lets try the right path."

<u>Surroundings of the goal</u>
Search for or recognition of a certain group of landmarks, namely the landmarks and views located next to the goal; The range of the relevant area "next to the goal" depends on the size of the area in question, that is if one is searching for a goal in a larger city, a global landmark (even if is not located directly at the goal) may be a good temporary goal. If the searching area is smaller, e.g. the goal is located within

the part of town or the campus where the navigator stands already, he/she should look for the goal's immediate surroundings as in the example below.

Example: "There seems to be a courtyard, here I'll have a look inside as I remember that the maypole was located in a courtyard."

2.3.3 Route knowledge

Route sequences

Itineraries are remembered; the sequence of actions known from the training of the route is repeated.

Example: "I have to turn right at the first and the second junction; afterwards I will turn left at the traffic light."

Search for landmarks

Search for a certain remembered landmark/view which usually constitutes a temporary goal or continuation of the route until the specific landmark (which constitutes the stop criterion) is reached; In the latter case, the navigator knows that he/she has to turn e.g. left at a certain landmark which means that he/she will not make the left turn until he/she sees this landmark.

Contrary to the next category, recognition of landmarks, subjects dispose of active landmark knowledge, they remember a certain landmark and search for it before seeing it on the way. Contrary to the search for known objects, subjects search for a specific landmark that they remember and name precisely before seeing it.

Example: "I remember that we passed through a gate, so I'm searching for a gate now."

Recognition of landmarks

The navigator does not actively search for a certain landmark or view, but recognizes the landmark/view once he/she sees it on the way and then associates a certain action with it (e.g. to turn left at the green house). Passive knowledge of the landmark/view is sufficient for the recognition strategy. The navigator walks on the supposedly correct route and either continues until he/she perceives a conversant landmark/view or currently uses a different strategy and the recognition may confirm or change this strategy.

Examples:

Recognition of landmark: "I'll turn right at the statue as I remember that last time I took the path to the right of the statue."

Recognition of view: "I'll turn right as I remember this view where I turned right last time."

House and building numbers

Usually the numbering scheme of house and building numbers follows a logical sequence and then provides route and approximate distance information.

Here, it means particularly the usage of building numbers in order to recognize a logical system that can be used to navigate;

Example: "Here's building number 9, so building number 8 should be nearby."

2.3.4 Survey knowledge

Direction

The goal is supposed to be in a certain direction from the actual position. The direction describes the beeline connection between position and goal and can be egocentric or allocentric. Paths are chosen so that their combination leads into the right direction and finally to the goal.

Examples:

Allocentric: "The goal is at the left northeastern corner of the campus. As there is no path exactly going in that direction, I'll first go straight and will try to turn left later."

Egocentric: "The goal is to the far left from my actual position." (Often the navigator points into the described direction using his/ her outstretched arm.)

Exclusion principle

Reduction of possible sections to go to by exclusion of unfamiliar characteristics; for example, someone stands at a junction and has to decide which direction to take. He looks to one side and sees a view or landmarks that he has not seen before. Thereby he knows that this cannot be the way he took last time, otherwise he should have recognized this landmark or view. Accordingly, he can exclude this possibility and can decide on one of the remaining ways. This may also be applied to complete districts, e.g. "I know it is not within the industrial area."

However, it’s also possible that, during the guided tour, someone notices a landmark in a street exiting a junction and remembers not to take the street characterized by this landmark.

Further included into this category were the two following situations: The subject turns around and decides to go back to the last junction or even to the start because he thinks he is going the wrong way/in the wrong district. The subject decides to exclude a certain path because it leads to the campus’ border.

Example: “I’m sure that I haven’t passed the alley with the oak trees to the left so I will better turn right here.”

Location of the goal within the area

The goal is supposed to be located at a certain place within the area; Here, our goal, the maypole, was erroneously supposed to be located in the center of the campus or close to the commons which was supposedly located in the center as well. Subjects first searched for the center of the area in order to further localize the goal once in the center.

Example: “The maypole must be in the center so I will go to the center of the campus first.”

There are further survey knowledge categories providing common and meaningful strategies and structuring the area according to Lynch (1960). As the experimental area encompasses only two districts, there are only few conspicuous edges and nodes which are rarely used.

Edges

Linear elements that are not considered paths, usually boundaries separating two areas, e.g. walls, borders of specific land-use areas, large street splitting an area into several districts;

Nodes

Strategic points of a city, accessible and intensively used/frequented, usually point where people decide how to continue their route (strategic nodes); also a route’s starting point and/or destination, e.g. crossroads, street corners, familiar places where specific people meet (thematic nodes).

2.3.5 Number of strategies

All subjects use more than one navigation strategy. So, even at a short navigation task, subjects do not get along with one strategy. On average they use three to four strategies in order to cover an optimal navigation distance of about 570 meters, depending on environment and success.

We counted the number of different strategies used during one navigation, so returning to a strategy used before doesn't increase the number of counted strategies on this navigation.

On average, subjects used three to four different strategies both in R and VR (R: $\bar{x}$ = 3.26, VR: $\bar{x}$ = 3.49). Figure 10 shows that the number of strategies varies little with navigation environment and more with success.

In both environments unsuccessful navigators used significantly more strategies than successful navigators (see Table 11 and Figure 10).

	Successful		**Non-successful**		**t-test**		
Number of strategies used	$\bar{x}$	σ	$\bar{x}$	σ	p-value	df	Effect size
Navigation in R	2.9	1.09	3.94	1.39	.036	55	.83
Navigation in VR	2.88	1.1	4.24	.88	.001	55	1.37

Table 11: Number of strategies used depending on navigation success and navigation environment

There are two main reasons accounting for this: first, if the strategy currently used is successful there is less need to change to another strategy; second, unsuccessful subjects spend more time navigating and thus have more time to try different strategies.

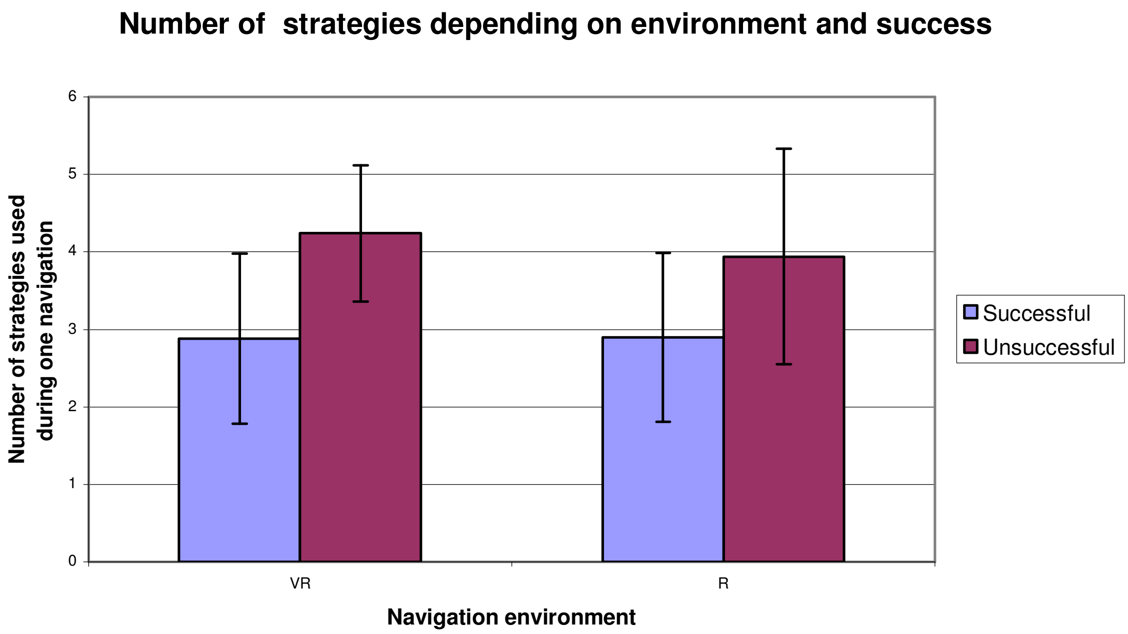

Figure 10: Number of different strategies used per navigation depending on environment and success, standard deviations

2.3.6 Strategies depending on navigation environment

Figure 11 shows the strategies that have been used separately for both navigation environments.

'Recognition of landmarks' and 'exclusion principle' are the favorite strategies in both environments. Actually, the three most frequent strategies are based on route and survey knowledge. Other popular strategies are 'searching for known objects' (landmark knowledge) and 'search for landmarks' (route knowledge).

One question was if the navigation process differs from real to virtual environments, i.e. if the same strategies are used in both environments?

Figure 11 shows that the same categories of strategies were used in reality and virtual reality. Moreover, the percentages of subjects using the specific strategies correspond exactly or prove to be similar in both environments.

Both strategy distributions of all strategies and frequencies of single strategies were compared and tested with chi-square-tests. None of the differences between real and virtual navigation environment proved significant. In both navigation environments, the strategy distribution (see Figure 11) differs significantly from equal distribution, i.e. there are significant preferences for specific navigation strategies.

It results that environment doesn't have a significant influence on strategy use.

These results imply that the navigation process is comparable with respect to its strategies in both R and VR. Furthermore, half of the subjects that trained in R (groups A+B) also used the same strategies as the other half (groups C+D) that trained in VR. Thus, the strategy comparability accounts for both training and navigation environment, i.e. strategy usage is independent of training and navigation environment. Our hypothesis referring to this is thus confirmed.

Navigation Strategies in R and VR

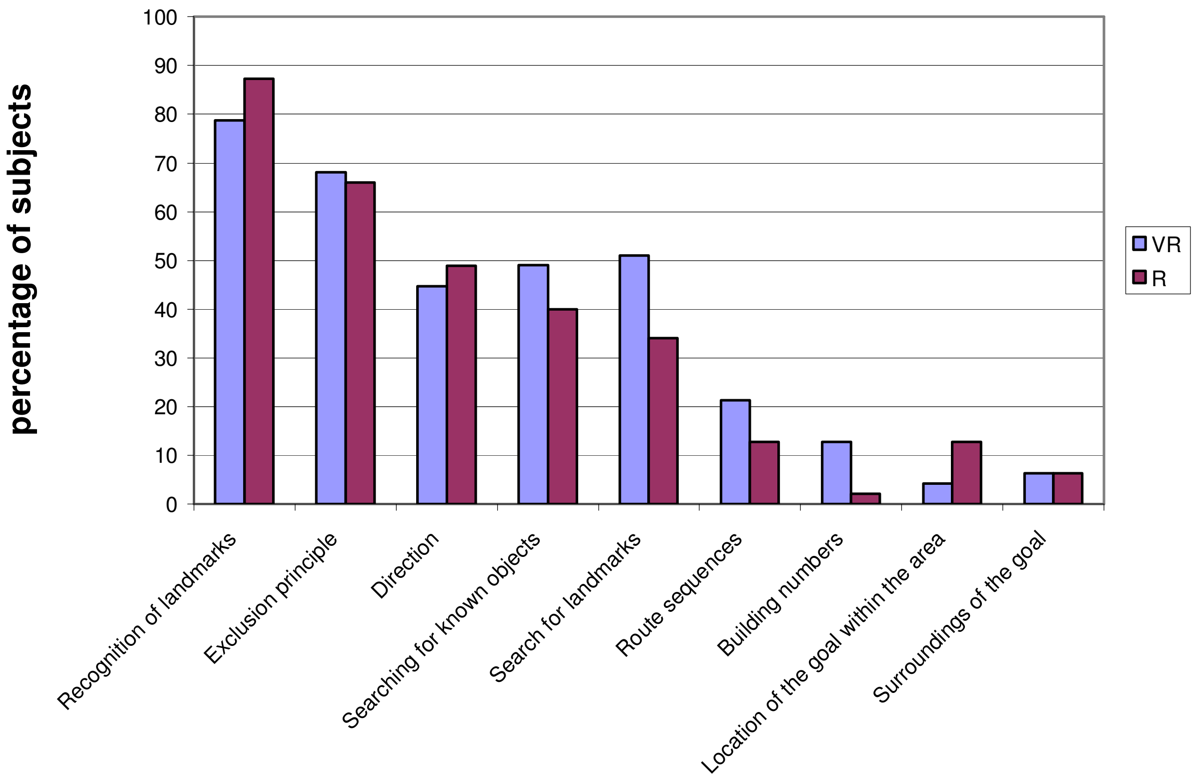

Figure 11: Navigation strategies: percentage of subjects using the specific strategies depending on navigation environment

2.3.7 Strategies and success

The use of strategies is related to success (see Figure 12). Nevertheless, testing the frequency distribution of all strategies, the chi-square-test does not reveal significant differences for navigation success (comparing true and expected scores in case of equal distribution between the successful and the unsuccessful sample). There are some strategies that are frequently used regardless of success like recognition of landmarks and route sequences.

However, differences emerge when testing the equal distribution for the usage of single strategies. One strategy is clearly preferred by successful navigators. The strategy direction is used by 58 percent of successful navigators, whereas only 30 percent of the unsuccessful ones used it. This difference proved to be significant in VR (chi-square-test comparing the frequency of direction usage between the successful and the unsuccessful sample: p= .04), but not in R, and thereby partly confirms our hypothesis concerning the quality of direction strategy.

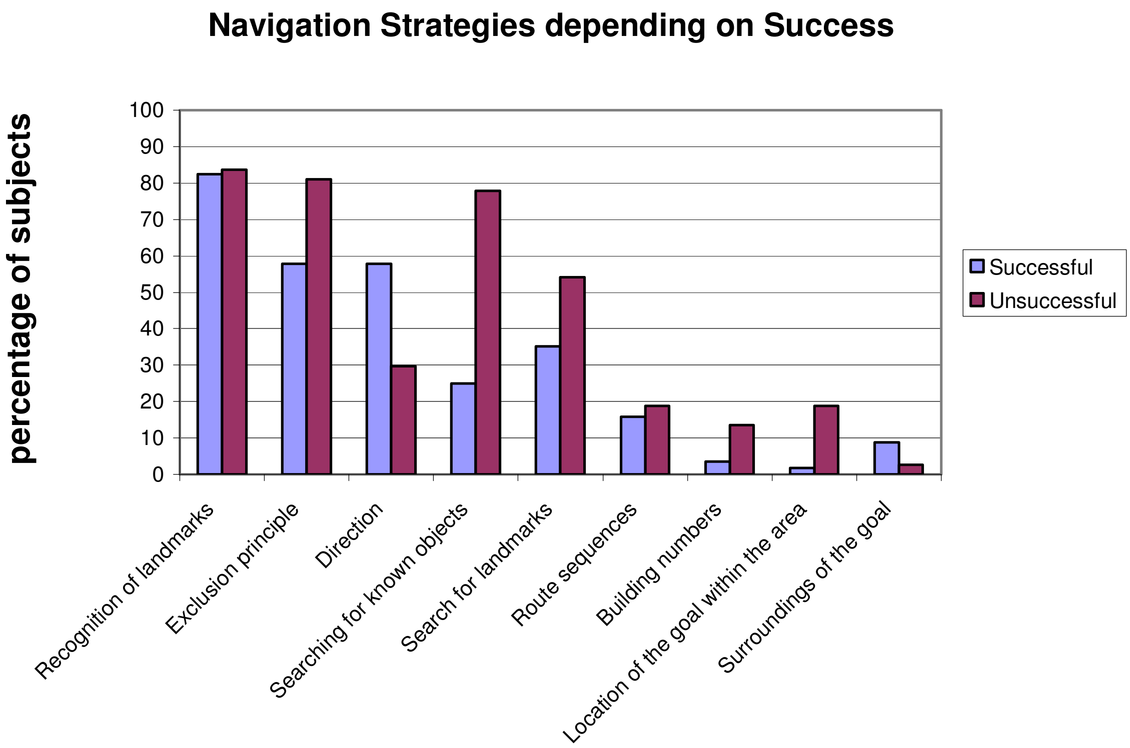

Figure 12: Percentage of subjects using a navigation strategy depending on success

Another strategy seems to have different effects or is employed in different situations depending on navigation environment (see Figures 13 and 14). This is the case for the strategy exclusion. In VR, significantly more unsuccessful navigators employ this strategy (chi-square-test: p=.03). In R however, this strategy is used likewise by successful and unsuccessful navigators.

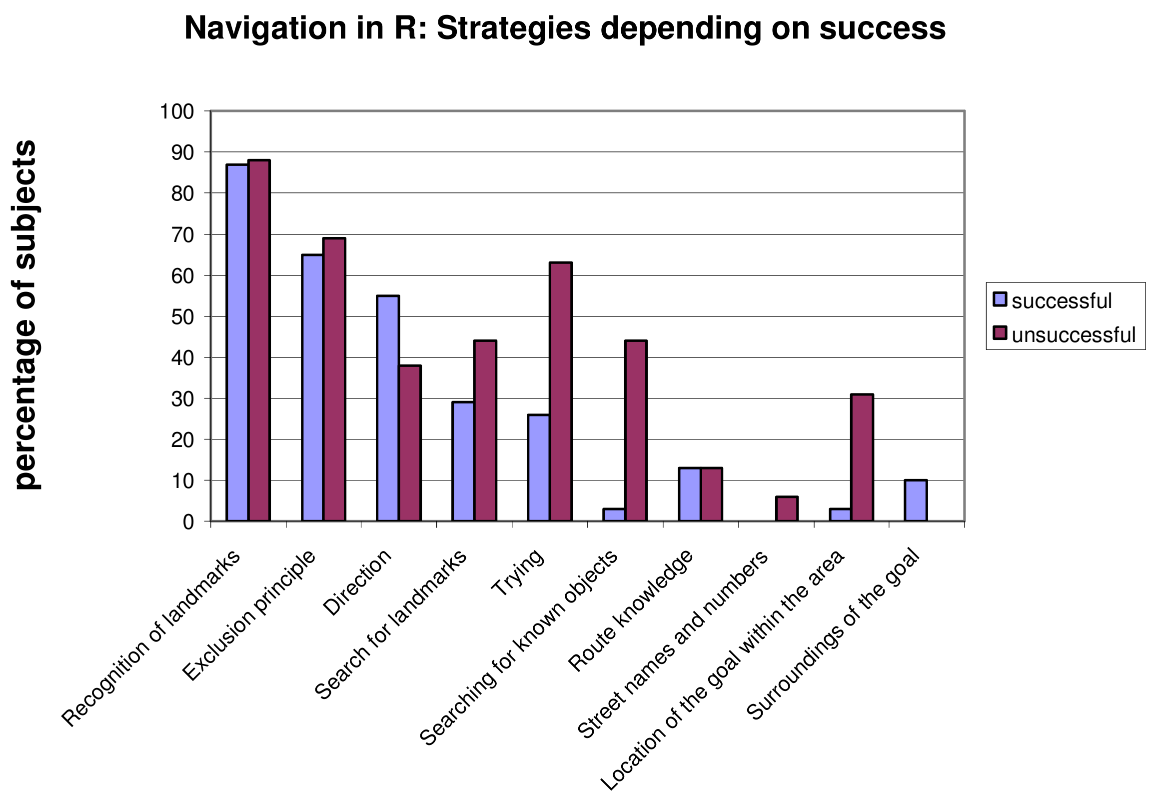

Figure 13: Navigation in R: Percentage of subjects using a strategy depending on success

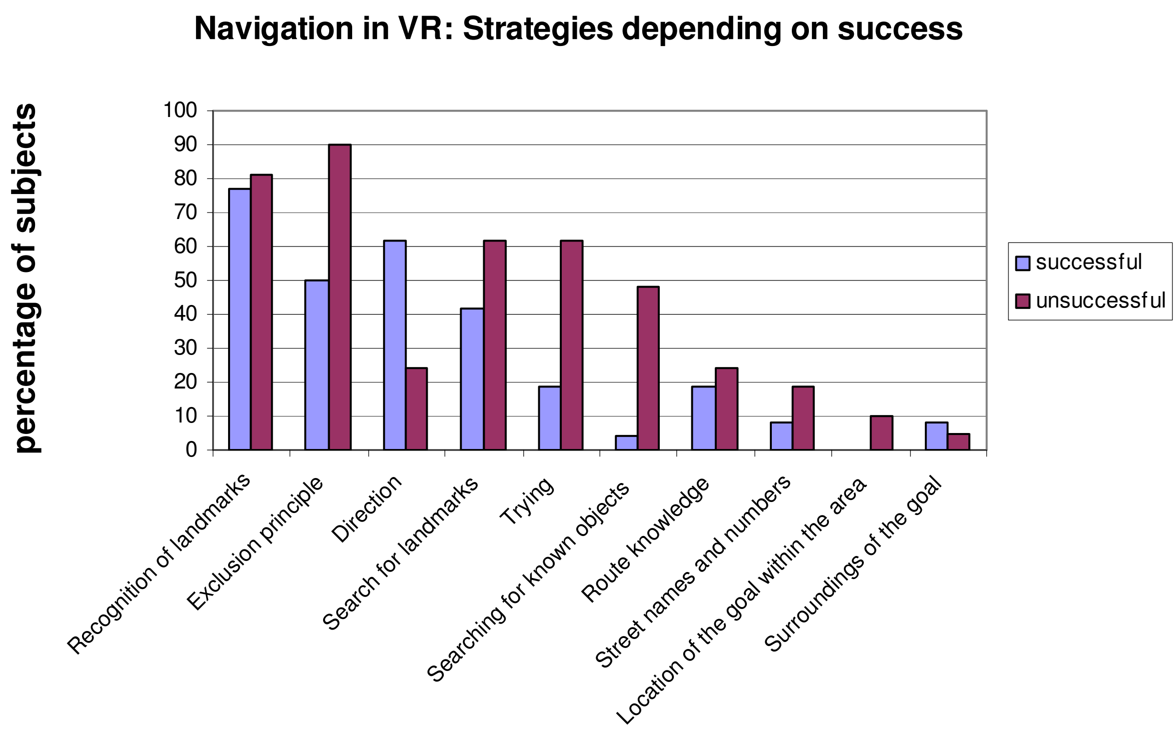

Figure 14: Navigation in VR: Percentage of subjects using a strategy depending on success

Other strategies are preferred by unsuccessful navigators or don't lead to the goal. The differences are significant for the strategies trying and searching for known objects ($p<.001$) in R and VR. The same tendency accounts for the strategies search for landmarks, street names and numbers, and location of the goal within the area. The frequencies of the last two strategies are too small to be tested.

In VR three strategies are used significantly more often/less by successful navigators, whereas this applies only to one strategy in reality. This raises the question whether the virtual navigation situation differentiates more between adequate or inadequate (towards subject's abilities and situational necessities) strategies.

2.3.8 Landmarks

The strategy analysis reveals the importance of landmarks for navigation. Three out of the four most frequent strategies deal with landmarks and thereby show that landmarks can be used for navigation in many different ways:

- Route decision due to known landmarks or views: recognition of landmarks
- Route decision due to unknown landmarks or views: exclusion principle
- Search for specific landmarks
- Search for known objects
- Street names and numbers
- Surroundings of the goal
- Confirmation of the chosen route: by recognition of a known landmark after route decision

The strategies are described in detail in the preceding Chapters 2.3.2–2.3.5.

About one third of the subjects also used movable landmarks, like dustbins, motor cycles, construction sites, barbecues, and outside furniture.

For navigation in R, this was not problematic because most of the cited movable landmarks were actually not relocated during the experiment or just replaced by other similar objects. However, these objects were not depicted in VR, thereby confusing the few subjects who were seriously searching for them. Once this was recognized by the experimenter, he told the subject that this object was not depicted in VR (incidence was about five times).

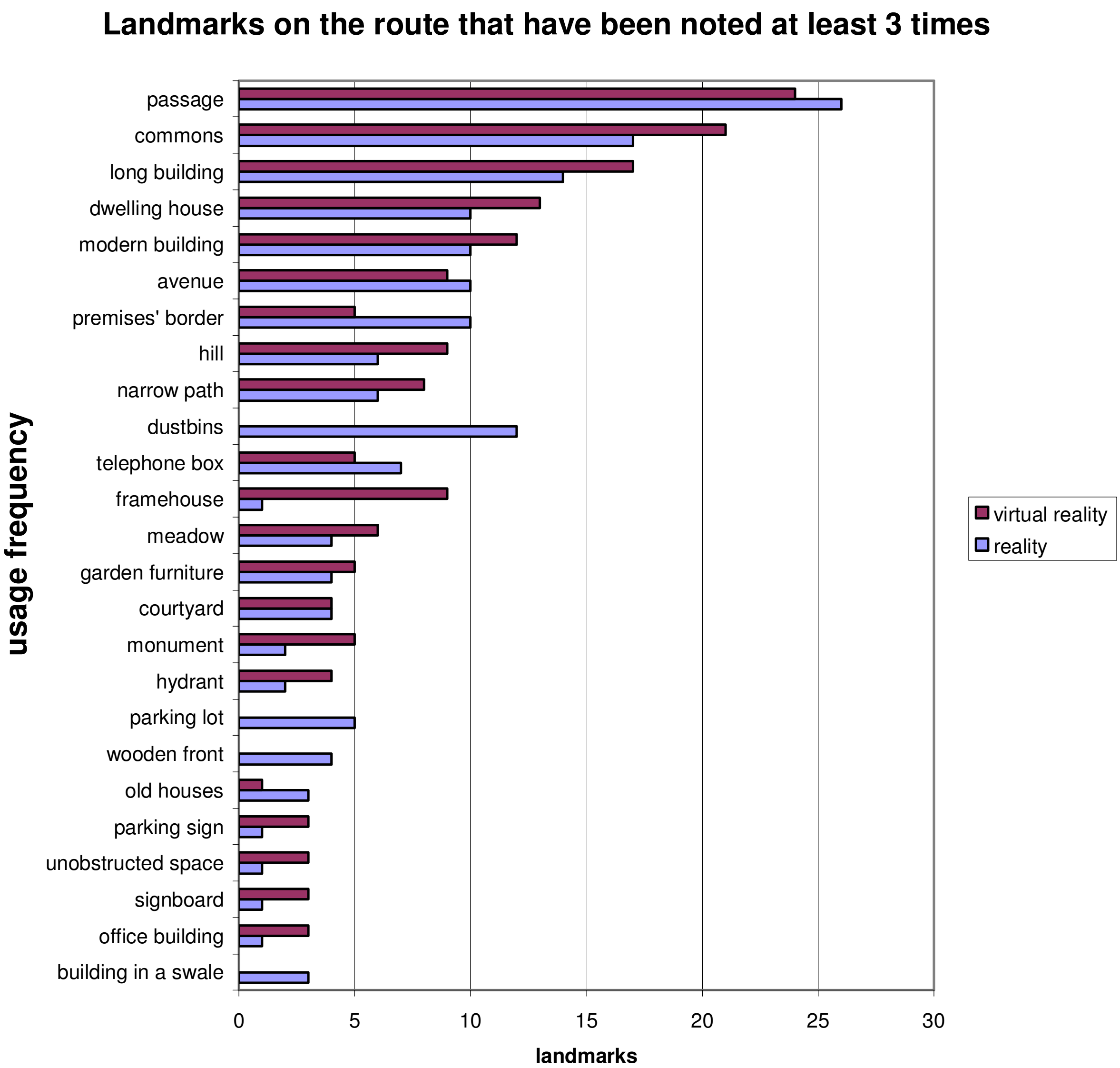

Figure 15: Landmarks that subjects used at least three times

Differently sized elements can constitute a landmark. For example, some subjects use a building as a landmark whereas others may use only certain elements or characteristics of this building. Contrary to that, the building may be a part of the whole configuration of various buildings that is perceived as a landmark.

The following Figure 15 gives an idea of the landmarks used by subjects in this experiment. Analyzing these landmarks with regard to the objective features of landmark definitions, results in the fact that most cited landmarks are created naturally (91%), contrast with the environment (65%), are highly visible (61%), and stationary (91%). The employed landmarks take up different positions on the route:

39% of landmarks are located outside the route (and well visible), 30% are located on the route, and another 30% are located on the route and at a decision point.
Comparing the use of landmarks in R and VR, I noticed that differences decline with the increasing usage frequency of a landmark, i.e. the more often a landmark is used, the smaller the difference between both environments (see Figure 16). Landmarks that were frequently used and that existed in both environments were used with approximately the same frequency in R and VR. The landmarks in VR were used slightly more often than in R, probably because there are fewer landmarks available. The movable landmarks, nonexistent in VR, were used only in R.
Another interesting point was the differing designations for various landmarks. For example, one building was named “building six”, “long house”, “old building”, and “church”. Many landmarks had a number of differing names during the experiment.

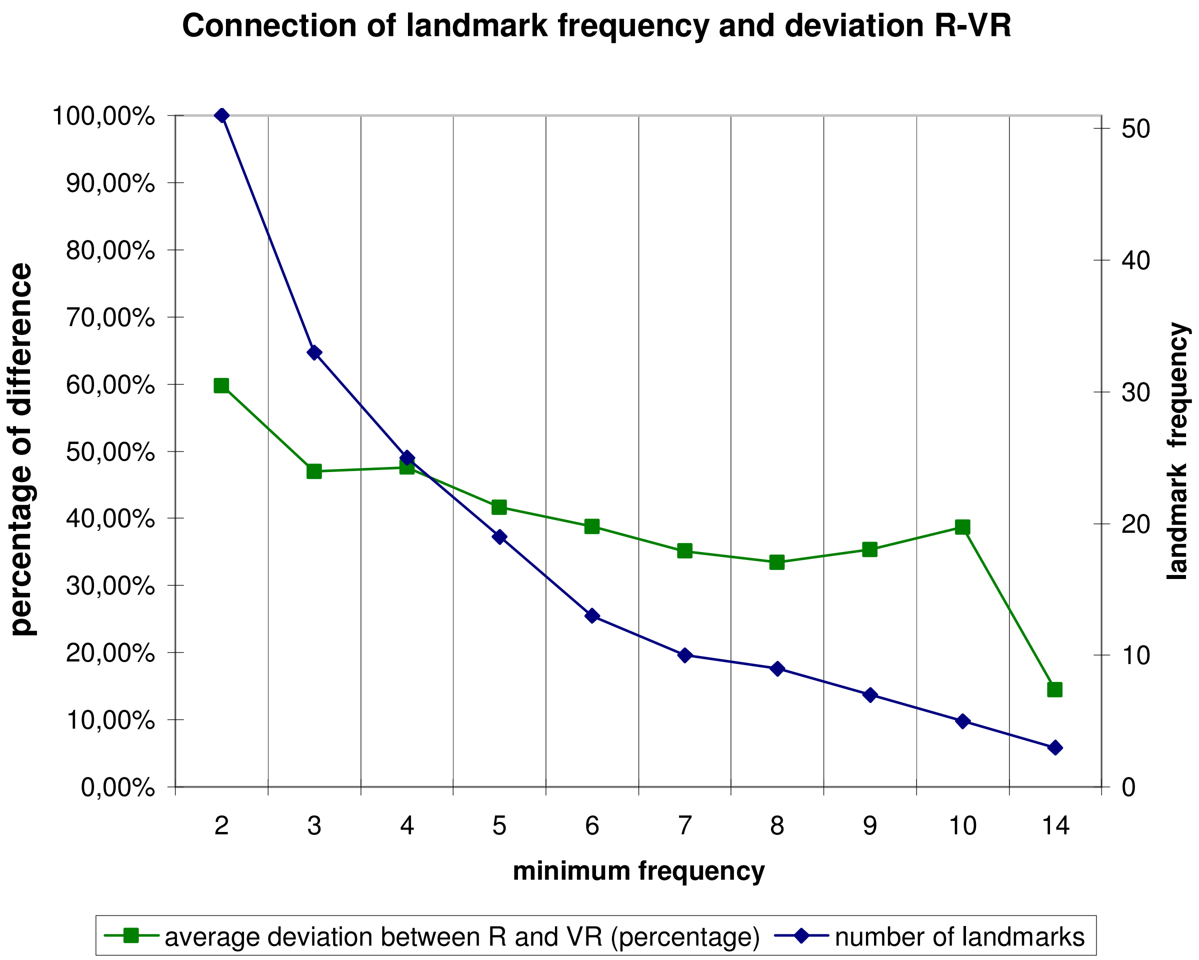

Figure 16: Connection between landmark frequency and average deviation between R and VR

2.4 Discussion: Navigation performance

2.4.1 Effects of training and navigation environment

The design of the experiment (depicted in Table 12) was created in order to investigate the effects of training and navigation environment on navigation performance (success and duration).

Experimental group	**A** 15 subjects	**B** 13 subjects	**C** 15 subjects	**D** 15 subjects
Training	R	R	VR	VR
Break	1 week	1 week	1 week	1 week
Navigation 1	R	VR	VR	R
Navigation 2	VR	R	R	VR

Table 12: Experimental design (R: reality, VR: virtual reality)

The **training environment** has a significant effect on navigation performance in reality. Subjects who have trained in R perform significantly better when navigating in R. However, their performance in virtual reality does not differ significantly from VR trained subjects. Thus, the reality training environment facilitates subsequent navigation in reality, but not in virtual reality. Apparently, the additional spatial knowledge acquired during the reality training (compared to VR training), constitutes an advantage only if the following navigation task takes place in R as well. However, training in VR does not effect higher navigation performance in VR.

Both related hypotheses can be partly confirmed. The hypothesis that training environment has a significant effect on navigation performance can be confirmed for navigation in R. The hypothesis that the congruence between training and test environment leads to higher performance can be confirmed for the real training and test environment.

Navigation environment has a significant effect on navigation performance if the preceding training was realized in R, but not if training was realized in VR. The R trained groups retrieved the goal significantly more often and faster when navigating in R compared to navigation in VR.

The experiment shows that navigation results obtained in VR cannot be put on a level with performance in R. Navigation in R was easier for all experimental groups. This raises the question if there is a function-relating performance in both environments, i.e. if a certain performance in VR equals performance in R once it is improved to a certain degree. It would be convenient to have a function to bridge this difference; however, it will be hard to develop a good one. As described in Chapter 1.9, there are various groups of variables influencing spatial knowledge acquisition (virtual reality interface, environmental features, exposure, training procedure, subject's characteristics), but also various methods to measure performance (e.g. direction and distance estimation, route retrieval). These variables potentially moderate the spatial knowledge transfer process. Therefore, I consider it to be very difficult to develop a function validated for or adapted to the above mentioned countless variations of spatial knowledge acquisition and inquiry methods.

Because of this and because of high variances in this experiment, it is just possible to indicate a tendency: most subjects show better navigation performance in R. This is also the conclusion of Péruch, Belingard & Thinus-Blanc (2000) who reviewed a large number of studies.

They tested a real training group and a virtual training group first in R, then in VR. Comparing both training groups, the real group performed better in both test environments just like group A (real training group) in my experiment.

However, in my experiment only the virtual training group showed similar (navigation) performance, whereas in the study by Péruch et al. (2000), only the real group showed similar performance in both test environments. The different performance measures may be one reason for this difference. Finally, both experiments agree that a real training environment leads to better spatial representations and performance at spatial tasks, but still they confirm that the transfer of spatial knowledge is possible from R to VR and vice versa.

Transfer of spatial knowledge between reality and virtual reality is possible in principle but with different levels of performance, more specifically navigation performance. Performance of direction and distance estimation was found to be similar in R and VR by Ruddle, Payne & Jones (1997) who replicated Thorndyke & Hayes-Roth (1982) real environment results in a virtual setting.

I noticed both large interindividual and intraindividual differences. Within one experimental condition, some subjects retrieved their route and goal immediately, whereas other subjects were completely lost. Change of navigation environment could cause the same situation within one subject thereby interrupting the constancy of his/her navigation performance.

These results raise two general questions:

1. Why do subjects perform differently, mostly weaker, in virtual compared to real environments?

Assuming that the reasons are based on differences between both environments, I will focus on how spatial knowledge acquisition and navigation differ in R and VR. Although our vision dome is an excellent tool which provides an immersive and detailed version of our campus, it does not replace the real environment with regard to all aspects. At the time of the experiment, spatial information was provided by means of visual cues only. The existing objects, buildings, paths, landscape, etc. in VR differ barely from their counterparts in R, but there are still some details that are not depicted in VR. However, some of those neglected details, particularly movable objects, turned out to be frequently used landmarks. Many subjects used e.g. a series of colored dustbins standing at the edge of the path or a couple of motorcycles parked under a gate as landmarks in R. Some subjects missed these objects in VR at least as confirmation to be on the right track as these landmarks are not located at important decision points.

Other sensory cues that may function as or add up to the perception of a landmark were not considered. Right now, a treadmill is installed that will enable us to provide motor cues at future experiments. This natural movement possibility is expected to improve navigation results in VR. At the time of the experiment, movement in VR was more passive than in R, both during training and during test phase. The means of control was a computer mouse which was operated by the experimenter according to the subject's orders. At the pilot study I noticed that many subjects had a hard time moving with the computer mouse in VR. In order to reduce the necessary attention for the movement action itself and to avoid effects of the subjects' different mouse control capabilities on navigation performance, I decided to have the experimenter operate the computer mouse. Movement in VR was less interactive, therefore more passive. In the literature there are differing opinions and results with regard to the effects of interactivity on spatial knowledge acquisition. Allen & Singer (1997) show that it depends on the environmental features if interactivity has an effect on spatial performance. In the non-distinctive landmarks version of VR they found that low interactivity even leads to better distance estimations.

Furthermore, movements in VR are less flexible than in R. For example turning the head takes longer and it is difficult to orientate while turning around in VR because the degree of present turning is not evident to many subjects. This may be the main reason why subjects turn around less frequently in VR. Looking to the side or turning around, often done for a quick moment only, provides additional visual cues and useful survey information. The lower number of turnings in VR are probably an important disadvantage when orientating in VR. If possible, the variable “turnings” should be controlled in future experiments.

2. What are the consequences of differing navigation performance in R and VR?

The comparability of spatial behavior in reality and virtual reality is the prerequisite for generalizations of results gained in virtual realities to real environments. Disposing of the virtual version of a really existing environment, we have the rare opportunity to directly compare navigation behavior in a real and virtual version of the same environment.

Recently virtual realities have been frequently used in human spatial research. However, my results, obtained in a very well realized virtual environment, show that comparability of navigation performance results cannot be taken for granted, but have to be investigated within the specific VR. Of course, results obtained in one kind of virtual reality (here the vision dome picturing a university campus) cannot easily be generalized to virtual realities in principle (Allen & Singer, 1997). Nevertheless, the vision dome is currently one of the best means to depict virtual environments. Navigation performance results obtained by other systems are likely to differ even more from R than those obtained in the vision dome.

When using virtual realities as a training tool, it should be considered that spatial knowledge acquisition and transfer possibilities to R are not on the same level as training in R. It would be interesting to research whether further training with the tool VR can improve transfer performance. In cases where training in R is not possible at all, training in VR is surely a good alternative to pure map studies, as results in much better performance than without training (Popp, 1995).

2.4.2 Sequential effects of navigational environments

Performances of each subject's first and second navigation are related. They correlate on a low, but significant level, i.e. someone who found the goal at first navigation is likely to retrieve it at second navigation as well. The majority of subjects show a certain level of consistent performance. Accordingly, the number of subjects who found the goal did not rise significantly from first to second navigation, which contradicts my learning-effect hypothesis.

Although the first navigation was expected to provide a good training opportunity, many subjects could not improve navigation performance from first to second navigation. At the time of the first navigation, subjects already knew about the experiment's aim (at first subjects thought that it dealt with landscape design) and, in addition, the time gap between first navigation and second navigation was shorter (just a few minutes) than between training tour and first navigation (one week). Here, my expectations could not be confirmed. One possible explanation is that change of environment reduces the learning effect. Another potential reason could be that navigation abilities are relatively constant characteristics. However, less than two thirds of my subjects showed consistent performance, the others improved or decreased in performance. Thus, the first mentioned reason is probably more important which makes clear that transfer possibilities of spatial knowledge from the real to the virtual environment and inversely are limited.

2.4.3 Embedded Figures Test

Results in the EFT reveal a broad range of levels and correlate significantly with quite a number of variables (navigation performance in VR and R as well as personal variables).

Personal variables like “young age”, a long experience in orientation and high education correspond to good performance at EFT. One reason for this might be that EFT tasks are generally related to theoretical problem solving and to certain kinds of geometric tasks at school. Young age and higher education mean that time distance

to school is shorter and that training was more intensive. Witkin (1971) also reports an increase in field dependency after a plateau of field independence in young adulthood. Higher educated people are mostly better trained at theoretical, paper-based problem solving. In particular, abstraction is both needed to solve the problems at EFT and constitutes a major educational aim.
The EFT correlates significantly with most measures of performance. The contiguity between EFT and navigation performance in both environments (R and VR) indicates that the perception style, measured by EFT, has similar effects on navigation in both environments. However, the EFT correlates higher with navigation performance in VR. This difference was also found by Conrad (2001). Probably the ability to distinguish objects/geometric forms from their background is more important for navigation in VR than in R. Field independent people (EFT high scorers) are able to isolate one landmark from the whole view in order to memorize it for navigational purposes.

The gender specific EFT results coincide with other authors' results in various paper-and-pencil-tests of spatial cognition (e.g. Quaiser-Pohl, 1998): men scored significantly higher than women. However, Quaiser-Pohl (1998) noticed that scores and the amount of differences depend on various factors, among other things on the nature of the test (higher gender differences in speed tests). The EFT is a speed test, which enlarges the gender divergence.

I conclude that the EFT are related (more in VR than in R) to navigation performance in both environments. However, correlations and shared variances are much lower than in Conrad (2001).

2.4.4 Sociodemographic factors

2.4.4.1 Previous experience

The question was which personal variables have an effect on navigation performance. As practice is usually the best way to improve one's skills in various fields, it was supposed that practice in orientation and navigation improves navigation performance during an experiment providing an ordinary navigation situation.

Practice was operationalized by general questions about the subject's personal navigation frequency and more specifically about professional or spare-time activities typically including navigation practice.

Indeed, results show that frequent exposure to situations in which someone has to orientate him/herself and most navigation performance measures correlate on a low but significant level. Furthermore, questions asking for specific navigation experiences correlate with navigation performance on about the same level as the EFT results. That means that a few questions requiring subject self-evaluation reach the same correlation/contiguity level as a written test.

Assuming that these questions are a reliable and valid operationalization for navigation practice and subjects are able to indicate their activities and evaluate the amount of navigation experiences, results show that the principle "learning by doing" applies to navigation abilities as well. More specifically, these findings confirm that good navigation practice in everyday life leads to higher navigation performance at the experiment.

Quaiser-Pohl (1998) who used slightly different measurement methods also found a contiguity between previous spatial experiences and actual spatial cognition test performance. She measured spatial experiences asking for subjects' self-evaluations regarding the frequency of spare time activities relevant for spatial cognition, distinguishing typical masculine, feminine, and neutral activities. Spatial cognition was tested with two paper-and-pencil tests namely "Schnitte" (slices; Fay & Quaiser-Pohl, 1999) and "Schlauchfiguren" (tube figures, Stumpf & Fay, 1983). If previous spatial exercises fostered the development of spatial cognition, there should be a significant correlation between spatial activity frequencies and test scores. Results proved low, but significant correlations between so-called masculine activities and both tests ("Schnitte": $r=.30$, $p=.001$; "Schlauchfiguren": $r=.19$, $p=.0237$).

A higher number of previous orientation experiences, i.e. activities training spatial knowledge acquisition and usage, correspond to a higher level of spatial cognition performances, both in the practical navigation tasks in my experiment and the paper-and-pencil tests in Quaiser-Pohl (1998).

On the practical level, this means that people can specifically improve their navigation abilities by approaching navigation situations in unfamiliar areas instead of avoiding self-reliant movements. The implementation of these practical units however depends on everyone's motivation and courage to challenge one's abilities which often includes risking to get lost temporarily. I suppose that there is an interaction between navigation ability and readiness to approach navigation situations, i.e. good navigators approach unfamiliar environments unhesitantly because they are confident of their navigation abilities which involves further improvement of their navigation skills. Contrary to that, less confident navigators usually avoid unfamiliar environments or leave navigation up to their companions which keeps their navigation skills on a low level which does not encourage them to approach challenging navigation situations. The good news for low level navigators is that the results of this experiment further confirm that navigation is learnable.

2.4.4.2 Education

The subject's educational level correlates on a low level with measures of previous orientation experience.

Probably higher education implies a certain spatial flexibility, i.e. highly educated people often move to another town or country in order to study or to do a job in their specific field of interest. Another conjecture may be that highly educated people are rather open-minded to new things in general, which often implies going to new places and having to navigate in an unknown terrain. Furthermore, they are used to acquiring knowledge by themselves and usually are more familiar with foreign languages. So not only the amount but also the method of traveling provides further orientation experience. In my experiment, individual travelers dispose of significantly ($p<.001$) higher education.

Of course, causal relations may also go the other way around or interact. Coming into contact with other countries' cultures and languages may also encourage the study of foreign languages, geography, culture, and history.

Education does not correlate with navigation performance which I find interesting. In a study by Appleyard (1970), education had a strong impact on map production performance of subjects' home town. He found that subjects with college education made far less mistakes than subjects disposing only of primary education. I suppose that there are three main reasons accounting for the different correlation of education and spatial performance. First, there are larger differences between primary education and college education in Venezuela than between the variety of schools in Germany. Second, drawing a map requires some abilities that less educated Venezuelan people might not ordinarily practice. Finally, measurement methods differ in both experiments. Appleyard (1970) had his subjects draw a map, whereas subjects in my experiment had to retrieve a goal (navigation). Probably, the differences would be smaller in Appleyard's (1970) study if he had used a more common test, e.g. navigation.

2.4.4.3 Gender

Women retrieve the goal more often but not faster than men. The virtual reality seems to be a much better training environment for women, as women in those groups navigate significantly more often successfully than men.

Navigation success and the paper based EFT reveal dissonant results. Results reveal that women of our sample scored lower than men at the EFT but performed better at the navigation task. The performance measures, EFT score and navigation performance (success and duration in R and VR), correlate on a low to medium level. Thus, women's repeated lower results at paper-and-pencil-tests concerning spatial cognition or particularly field dependence (EFT) do not imply lower practical performance at navigation tasks.

I suppose that there are various reasons that can explain these differences between theoretical and practical performance. First of all, compared to navigation, a test like the EFT examines a more specific ability and characteristic (field dependence). On the contrary, a navigation situation or task in the field requires various abilities, but also allows for compensation, i.e. there are usually several possibilities to act in order to proceed successfully. Most people are quite flexible and robust if one strategy fails because strategies can be changed. Knowing about one's weaknesses enables one to develop alternative navigation strategies, e.g. a person who is not good at judging directions or to estimate distances can concentrate on landmarks and vice versa, thereby showing good performance in the field. Thus, there are abilities accounting for navigation performance that are not tested by the EFT.

Another possible reason to consider is that EFT high scorers are likely to dispose of good analytical abilities, which they might try to use for navigation as well. However, one important analytical strategy, precisely logical systems of house and building numbers, is not helpful in this specific terrain. There is only one named street and buildings do have numbers, but numbers don't follow any logical sequence. EFT high scorers may be a little disadvantaged if they try to use this logical system's strategy, which might reduce the correlation between EFT and practical performance. However, further data analysis shows that only seven subjects used the house and building number system and six of them had a test score below average. Thus, preference for analytical strategies that are hardly useful in the experimental environment cannot explain the differences between theoretical and practical performance. Probably analytical abilities used to solve the problems at EFT differ from those used when navigating with the help of logical systems like house and building numbers. Nevertheless, it is also possible that building numbers do not represent a logical system or that analytically thinking people (at least when solving the EFT) do not use logical systems during navigation.

Searching for reasons of gender differences in navigation after virtual training is much more complex. A comparison of men and women regarding potentially influencing variables, like sociodemographic factors, previous experiences, and interest in experiment, revealed significant differences concerning interest. At the first session, subject and experimenter estimated subject's interest. Both measures correlate significantly. At the second session, only the experimenter estimated the subject's interest. In order to compare interest at both sessions, the experimenters' estimations were used. Interest in the experiment was constant for most women whereas men showed higher interest at the first session (t-test comparing men and women, $p=.058$, men>women) and significantly lower interest at the second session (t-test comparing men and women, $p=.01$, women>men). Decreased interest at the second session could possibly be a mediating factor for performance or the result of dissatisfying navigation experiences.

Neither gender differences nor the subject's expectations towards their own navigation performance were the focus of my investigations, although it would be interesting to collect this data in a future experiment. Therefore, the following considerations are mere suppositions based on social psychology and on what experimenters noticed when observing subjects.

Due to social role allocation, most men may have specific expectations (in this context probably something like: “a man is a good navigator”) about the success to achieve in putatively men dominated fields like navigation. If, however, the result of his actions does not meet his expectations, he is likely to be frustrated by his failure to solve the task and to act according to his and implied others’ expectations. This might decrease his motivation for and interest in the experiment. Furthermore, causes for failure may be attributed to external reasons like experimental conditions. Causal attributions for navigation success or failure are an interesting topic that could be included easily in a new navigation experiment.

Nevertheless, correlations between the subjects’ interest and navigation performance are weak and non-significant, i.e. there may be other reasons for the men’s decreased interest at the second session.

Results further show that more women managed to improve from first to second navigation. More constant interest and their rather task-oriented attitude (“I’ll just try it out!”) relieved the pressure men probably felt after the first failure and may have facilitated training and navigation.

Another possibility for gender differences is that men prefer strategies that are not helpful in this specific terrain, e.g. the above-mentioned logical systems (street names and numbers) or location of goal within the area. Neither of those strategies works well at the experimental terrain. Using common knowledge about the location of the goal within the area is rather misdirecting. A maypole, which constitutes the goal, is usually found in the center of a district, here it’s located at the very edge. However, strategy analysis did not reveal any significant gender differences.

Our experimenters noticed that many participating women were more ingenuous, more curious, and more attentive than most participating men. Some men seemed to be rather interested in the technical features of virtual reality which could eventually absorb attention. However, they spent the same time navigating in virtual reality as the female participants. Many men seemed to be rather convinced of their abilities whereas many women were just curious and decided to try this new thing.

To sum up, mainly training and navigation environment have an effect on navigation performance, whereas the perception style has a low and navigation sequence (first navigation in R, second in VR or first navigation in VR, second in R) has no notable impact.

Effect sizes of significant differences in this experiment range from middle to high level indicating a reasonable, not just by chance significant effect of the independent variables. However, a single independent variable explains only 10 to 20% of the variance of navigation performance, which does not devalue its importance, but indicates that there is a larger number of factors influencing complex human behavior, like orientation and navigation.

2.5 Discussion: Strategies

The questions were, how do people manage to orientate themselves in an urban environment or, in other words, what kind of strategies and landmarks do they use in order to retrieve their goal? Are these strategies and landmarks used the same in a real and a virtual environment?

As described in the methods chapter, when taking the same route again and again, most people don't think consciously about navigation. That's probably why a few subjects had a hard time explaining their considerations at the beginning. However, most subjects quickly became used to talking about their considerations when choosing the next path.

2.5.1 Types of spatial knowledge

Although subjects in my experiment had very little training (they walked only once on the route) before searching for the goal at the navigation session, they used strategies based on all three types of spatial knowledge. This is in contrast to Siegel & White (1975) who proposed that subjects disposing of little training merely gain landmark knowledge. Siegel & White suggested that these types of spatial knowledge represent successive stages beginning with landmark knowledge (little training like in my experiment), continuing with route knowledge (further training), and finally reaching survey knowledge after a large amount of training in the area.

Contrary to that, my results clearly demonstrate that not only landmark knowledge, but also route and survey knowledge may be developed from the very first contact

with an environment. Results of both methods used, thinking aloud and strategy interview, show that the three most frequent strategies are based on route and survey knowledge.
Of course, not all subjects are able to do so and the amount and quality of all three types of knowledge are likely to improve with further contact. Nevertheless, frequency analysis of navigation strategies reveals that the most frequent strategies are based on route and survey knowledge, thus these are used even more often than strategies based on landmark knowledge.

As described in Chapter 1.6, I think and the results support that many people dispose of a potentially developing, but at a specific moment dominating kind of spatial knowledge.
For example, a knowledge dominance of landmark knowledge, the most likely at newly trained routes, does neither exclude the acquisition of route and survey knowledge at the early stage, nor the lasting dominance of landmark knowledge, despite further training for subjects who have a stable preference for landmarks or who just repeat the same route.

To sum up, my experiment's strategy analysis does not confirm the successiveness of three stages of spatial knowledge as supposed by Siegel & White (1975), but demonstrates that the proposed stages are rather types of spatial knowledge whose use depends on various factors (e.g. personal preferences and abilities, environment, training, also see factors influencing navigation performance in Figure 2).

2.5.2 Navigation strategies depending on navigation environment

Comparative analysis of strategy use in R and VR shows that neither environment (training and navigation environment), nor navigation sequence has a significant influence on strategy use. In R and VR, the same categories of strategies are used and, what is more, even the frequencies of strategy use (for every category) coincide approximately. Therefore, results imply that the navigation process is comparable with respect to its strategies in both environments. This is an important finding, as it empirically shows that experiments aimed at investigating the human navigation process can be performed with high quality virtual environments without restricting the representativeness of results to virtual realities. With regard to the navigation process, external validity is retained.

There are no gender differences, neither which contradicts several authors stating that women used more landmarks, whereas men used structural strategies.

For example, both Lawton (2001) and MacFadden, Elias & Saucier (2003) found that women used more landmarks for route descriptions whereas men preferred cardinal directions. Likewise, Neidhardt, E. & Schmitz, S. (2001) describe that girls rather develop a landmark pattern, whereas boys mostly develop a survey pattern of the experimental maze.

But previous research does not present uniform results concerning gender differences of landmark use. There are also authors who found that men profit from landmarks in an navigation environment more than do women (Cutmore, Hine, Maberly, Langford & Hawgood, 2000). Likewise, Gwinn, Fernando, James & Wilson (2002) revealed that men outperform women when learning a route on a map with landmarks but not when learning it on a map without landmarks.

I noticed two other phenomena whose causes are based on general psychological processes relating to perception, information integration and recall.

First, recognition (requiring passive knowledge) is easier than remembering (requiring active knowledge) which might be one reason for the higher frequency of this strategy.

Second, I noticed the impact of previous knowledge and concepts on spatial knowledge acquisition. The goal of the experimental navigation is a maypole which is usually located at a market or central place, which are usually both located in the center. Although, the maypole on campus is not located in the center, but in its northeastern corner, some subjects were convinced that the maypole was located in the center. In that case, the previous schema distorted the perception of the location of the maypole.

2.5.3 Navigation strategies and success

Nevertheless, there is one variable that is related to strategy use. Navigation success depends on the use of strategies. Regarding the distribution of all strategies, there are visually distinctive but not statistically significant differences between successful and unsuccessful navigators. The significant differences emerge when regarding the single strategies.

Our hypothesis that the strategy direction leads to success was confirmed, i.e. later successful subjects use the direction strategy significantly more often than subjects failing to find the goal in VR. This result agrees with Schmitz (1999) who found that route direction preferences at map drawing and route description tasks correspond to faster navigation and higher self-estimation of way-finding tasks.

Further analyzing the group of direction strategy users, I noted that significantly more (navigation) experienced subjects use the direction strategy. This means that a certain amount of navigational training may be needed to use the direction strategy and that other trained navigational abilities may further improve these subjects' performance in the experiment. Sixty percent of the successful navigators used this strategy. In addition, many of them used only one or two other strategies, which is below average concerning the number of strategies used. Therefore, I assume that their direction estimation was quite good. The next experiment asks specifically for direction estimations to make this point more clear.

As already said, a good direction estimation indicates the existence of at least a rough cognitive map. In addition, according to Downs & Stea (1982), we can assume that successful resolving of common spatial problems is sufficient proof for the match of the cognitive map to the real environment. This applies to most of our subjects. These are two evidences for a possible early development of cognitive maps at first contact with the environment.

There are other strategies that are significantly more often preferred by unsuccessful navigators (searching for known objects in R and VR, exclusion principle in VR). It is conspicuous that in VR, three strategies are used significantly more often/less by successful navigators, whereas this applies only to one strategy in reality.

This raises the question whether the virtual navigation situation differentiates more between adequate and inadequate (towards subject's abilities and situation necessities) strategies.

I suppose that the virtual reality situation further differentiates between subjects who know a strategy well, use it confidently even in an unfamiliar type of environment and

thereby are successful, and the other group of subjects who do not possess enough knowledge and exercise about their strategy and therefore have trouble transferring this strategy concept to VR.
Nevertheless, I cannot judge on the causal direction. It is possible that certain strategies lead to success (e.g. direction) more than others (here e.g. building numbers) or are particularly used by navigation experienced subjects (e.g. direction). But it is also possible that once lost subjects use certain strategies (e.g. searching for known objects), because other planning strategies are not available any more.
Supposedly, strategy use and navigation success interact.

The interaction between strategy use and navigation success may also be one reason why unsuccessful navigators use significantly more strategies. First, unsuccessful navigators navigate longer and thereby have more time to employ different strategies. Furthermore, navigators may use more strategies when noticing that strategies currently used are not successful. However, the causal relations may also go the other way around, i.e. the use of many different strategies, implying many strategy changes, may not lead successfully to the goal.
Besides, the number of strategies used may also result from personal characteristics or preferences. Therefore, I compared the number of strategies at successful and unsuccessful navigation within subjects (subjects who were successful at one and unsuccessful at the other navigation). During the successful navigation these subjects used 3,31 (mean), during the unsuccessful navigation subjects used 4,15 (mean) different strategies. The number of strategies at successful and unsuccessful navigation correlate on a low but not significant level (r=.313). Probably because of the small number of subjects included into those calculations, neither the t-test that could have proved the situation impact, nor the correlation that could have proved the personal impact were significant. Investigations with larger samples and more detailed analysis of subjects related to personal characteristics could further answer this question and check if there is an interaction between situation and personal variables influencing the number of strategies used.
Moreover, strategy change can be the result of flexible strategy usage as well. Flexible strategy usage means that the first used strategy was useful for this route sequence (e.g. search for a specific landmark that is reached at the end of this

sequence). However, this first strategy does not seem to be useful for the following sequence, because it cannot be employed any longer (e.g. because there is no following landmark remembered by the subject) or because the subject selects another (subjectively) best strategy for the respective route sequence from a pool of potential strategies. There are at least two possible reasons for strategy change which are difficult to distinguish when listening to the subjects' thinking aloud records.

Thus, different strategies may lead successfully to the goal, i.e. there isn't just one way of doing it. I think that strategies are adapted to a person's abilities and to the environment in question. This is possible if the route is trained by the navigator him/herself. However, if navigation is based on a map or on somebody else's route description, the navigator cannot always extract the relevant information for his/her preferred strategies. The next experiment investigates which strategies are implied by usual route descriptions and which kinds of route description are successful.

2.5.4 Landmarks

Landmarks are used within the scope of various important navigation strategies.
Differently sized elements can constitute a landmark. For example, some subjects use a building as a landmark whereas others may use only certain elements or characteristics of this building or contrary to that, the building may be a part of the whole configuration of various buildings that is perceived as a landmark.

The characteristics of the chosen local landmarks partly confirm current landmark definitions in the literature (e.g. Lynch, 1960; Steck & Mallot, 1997; Herrmann & Schweizer, 1998; Böhme, 2003). Contrary to two of these definitions (Bill, 2001; Werner, Krieg-Brückner, Mallot, Schweizer & Freksa, 1997) proposing that landmarks are stationary objects, some of our subjects also used movable landmarks. As described above, non-stationary objects can function as landmarks under certain conditions. A location's function as memorable feature could especially be confirmed. Surprisingly, all but one of the landmarks used were created naturally, i.e. they were not primarily constructed in order to facilitate navigation. However, there are only a few artificial landmarks available on campus because most people navigating there know the campus well because they live or work there. Therefore, subjects have do deal with naturally created landmarks that exist much more often. Many landmarks are located outside the route, but these landmarks are usually quite visible which ensures the landmark's perception. This agrees with Herrmann & Schweizer (1998).

In general it can be said that the chosen landmarks contrast with their respective environment and are highly visible. Many of these landmarks are located at unusual places (e.g. dustbins at the wayside, gate through a building, large turbine screw on the meadow), feature gaudy colors (e.g. yellow, red, brown, and blue dustbins standing side by side) or unusual forms and materials (large, bright wooden houses).

Of course, the importance of landmarks for successful navigation also depends on the environment and its richness and on the other possible navigation strategies.

Landmarks that were frequently used and that existed in both environments were used with approximately the same frequency in R and VR. The landmarks in VR were used slightly more often than in R, probably because there are fewer landmarks available. As landmarks are important navigation aids, the smaller total number of landmarks and the lack of popular movable landmarks in VR may be a reason for the weaker training effect and navigation performance in VR. Nevertheless, the lack of specific landmarks in VR was rarely noticed by my subjects. This corresponds to the results in a study by Jacobs, Thomas, Laurance, and Nadel (1998) who trained subjects to retrieve an invisible goal whose location was indicated by distant landmarks. Moving these landmarks and thereby changing relative distances and arrangement relative to the goal strongly affected performance, whereas just removing these landmarks had no significant effect on retrieval success.

Strategies based on landmarks are used with about the same frequency in both environments. Therefore, when identifying landmarks in VR, we should take into consideration the total number of potential landmarks. Frequent use of an object for orientation and navigation may mean that it is a good landmark or that there are only a small number of objects available. In the latter case, the quality of the resulting "landmarks" should not be overestimated.

This problem emphasizes the importance of providing enough relevant landmarks in virtual environments in order to make navigation process and success comparable to real environments.

Another interesting point is the differing designations for various landmarks. For example, one building was named “building six”, “long house”, “old building”, and “church”. Many landmarks got numerous differing names during the experiment. Many subjects used the same landmark but named it differently. The experimenters often got the impression that subjects’ associations evoked at sight of the landmark lead to specific designations. Here, the subject’s experiences and background might be very important, e.g. a passionate mountaineer called the large wooden dustbin hut an alpine hut, whereas a hobby gardener thought of a garden shed.
High variation of landmark designations is one of the problems at the use of other people’s route descriptions. For example, if someone told me to turn right at the “church” (actually building six) on the campus, I would probably pass the so-called church without turning and continue to search for the church. In urban environments this happens often when a route description is based on exiting streets. Someone is told to turn at the third street left. When he gets to the first exiting street, actually a pedestrian and bike lane, he wonders whether or not this lane is included in the describer’s street definition. In order to further investigate this problem and the topic route descriptions, our next experiment researches the production and usage of route descriptions.

3. Second Experiment

3.1 Methods

3.1.1 Introduction

Route descriptions are a common navigation aid, but do not always lead us safely to our goal. When reading or listening to its description, the route sometimes still appears to be quite easy. However, once at a decision point on the route, navigators often wonder about the specific meaning of the route description components (e.g. equivocal descriptions of landmarks and junctions) because they lack the implicit knowledge of the author of the route description.

Although other navigation aids, namely navigation systems, are improving and becoming more popular, route descriptions remain a widespread navigation aid. They are often written or drawn and sent to clients or friends. Spontaneous verbal route descriptions are given when asked on the phone or in the street. A couple of years ago, companies and institutions started to publish route descriptions (how to reach their offices) on their homepage in the world wide web.

Despite the strong importance of route descriptions in everyday life and the apparent difficulties to produce good route descriptions, only a few authors (e.g. Denis, 1996, see Chapter 1.8) investigated the production and usage of route descriptions. Probably the qualitative data of route descriptions and its difficult and time-consuming analysis kept most researchers from exploring the subject “route description”.

In this experiment, I focus on route descriptions according to Herrmann & Schweizer (1998, see Chapter 1.8). The aim of these route descriptions of recently trained routes is to enable somebody else to follow the described route to the goal. I investigate production and usage of route descriptions in a field experiment featuring a natural setting (urban environment) and an ordinary context (tasks involving giving verbal and written route descriptions to somebody else, or to find a goal with the help of a route description).

In addition to route description production and navigation based on route descriptions, this experiment investigates the subjects’ abilities to directionally locate goals of newly trained routes. This topic results from the first experiment where the use of the navigation strategy "direction" was considered to be an indicator that the user had developed at least some survey knowledge of the newly trained area.

Finally, the topic "correspondence of subjective and objective performance measures" is investigated and discussed in various fields of psychological research (e.g. social psychology, developmental psychology) and practice (industrial and organizational psychology, e.g. evaluation of an employee at work by the superior and by him/herself). In everyday life, people consider themselves to be good or bad navigators. However, the basic definitions may differ as well as the quality of self-evaluation. As this experiment provides objective evaluations of navigation performance, I can compare objective and subjective evaluations of navigation abilities by asking subjects for general and specific evaluations of their respective performance.

I begin with the motivation and questions of this experiment. Afterwards, I enumerate upon the dependent and independent variables and continue by describing the sample. Further on, I explain the design and my expectations towards results (hypothetical assumptions). Then I describe the sequence of events and thereby explain the single parts of the experiment. At the end of this chapter, the data recording methods are described.

3.1.2 Motivation and Questions

Route descriptions

Despite their importance, route descriptions have been rarely investigated. Relevant questions ask, what a route description should look like in order to enable the user to navigate successfully, if there are essential and redundant pieces of information and what they are, and if there is a universal description that most people (with cognitive concepts based on the same culture) consider useful.

Thus, this experiment investigates the composition and quality of ordinary route descriptions.

Route descriptions based on landmarks or route sequences

The question is if route descriptions based on a specific class of components are better than others based on a different class of features. This experiment is designed in order to compare two popular, but different classes of route description components, namely landmarks and route sequences.

Landmarks contribute to orientation in space by facilitating orientation and navigation at potential decision points and further confirming the route. Local landmarks are particularly important at decision points, because landmarks and spatial actions are often related to each other (a route description may indicate to turn at a certain landmark) and therefore local landmarks help to make a decision at the present position. Local landmarks can be perceived only when being close to or at the decision point, whereas global landmarks can also be perceived from far away, usually during some or the whole navigation and thus may support navigation at more than one decision point. Both local and global landmarks are useless if their description is not good enough so that the navigator cannot recognize the landmark. Often landmarks are only enumerated, but not further described which makes it difficult for the navigator to recognize the landmark without the speaker's implicit knowledge.

Empirical results confirm the importance of landmarks as way-finding aids. For example, Jansen-Osmann (1998) had subjects train and navigate either in an labyrinth featuring landmarks or in the landmarkless version of the same environment. The group of subjects that could use landmarks for navigation needed significantly less training sessions than the group training in the non-landmark version.

Route sequences indicate where (number of street, e.g. first, second) to do something (to turn right/left, continue straight on). That seems to be easy as most people are able to count and can follow simple instructions, like right/left/straight. However, the direction giver usually does not explain how he/she counts the off-going streets which may complicate the instruction to turn left at the third street in equivocal street systems. For example, the navigator needs to know if the speaker counted small paths as well. Once the sequence of spatial actions becomes unclear, the navigator is unlikely to find the goal with this route description. A further disadvantage is that route sequences do not confirm a navigator's route choice.

Now, do route descriptions based on landmarks facilitate navigation more than route descriptions based on route sequences?

Landmarks and route sequences are often included in route descriptions and used as navigation strategies. Another navigation strategy that was used by some subjects at the first experiment and that could be included into route descriptions as well is direction.

Direction estimation

Although subjects of the first experiment were unfamiliar to the environment, the strategy ‘direction’ led many subjects successfully to the goal. But how about the other subjects?

As subjects were asked for the present strategies used at every decision point, subjects thought that perhaps it was expected to report local cues, i.e. cues that help to make a decision at a specific position, but not more general direction knowledge that supports navigation at more than one decision point. However, at the end of navigation, subjects were asked additionally to sum up which navigation strategies they used. At this more general question, subjects could also add strategies, not mentioned before. To sum up, it is possible that many subjects used the strategy direction for navigation, but some of them do not report it in order not to contradict the assumed expectancies.

I also don’t know whether the other subjects preferred non-direction strategies because they were not able to estimate directions or if they were actually able to give good direction estimations, but just didn’t use them as navigation strategy. If the first assumption was correct (many subjects are not able to estimate directions), many subjects would show poor performance when asked to indicate directions. On the contrary, if the second assumption was correct (many subjects are able to directionally locate landmarks/goals), many subjects would show good performance when asked to indicate directions. Of course, it remains to be defined what “many people” and “good direction estimation” actually means. Thus, in order to decide on one of the above assumptions and to learn about subjects’ abilities to indicate directions in a newly trained environment, I could encourage subjects to use the strategy direction and measure navigation success or, more directly, I could ask subjects to estimate directions to presently not visible landmarks or goals and measure the deviations from the correct direction. In order to avoid a large number of alternative explanations, I decided to directly measure direction estimation performance and to investigate the question on how precise all subjects' direction estimations are in an unfamiliar environment.

As described above, navigation and direction estimation performance during the experiment are measured by the experimenter. Performance evaluations by the experimenter consider only the subjects performance shown at the experiment. If measurement methods are valid, objective and reliable and common rating errors avoided, this is a good and frequently used method to learn about subjects' behavior. However, the subjects' behavior in further situations and in everyday life is not considered.

Instead of causing subjects to show relevant behavior and evaluating it by technical devices or experimenter observation, we could also ask subjects themselves to evaluate their own behavior and abilities.

Self-evaluation

Self-reports are a good method in considering previous behavior. In addition, the self-evaluation of one's behavior is related to someone's personal concept of him/herself. Thus, self-evaluations also reveal information about someone's general self-confidence (given that the evaluated abilities are important for someone's self-confidence). If experimenter ratings and self-evaluations can be compared, we also learn about one's ability to observe oneself and to evaluate own behavior and abilities.

Nevertheless, self-reports should not be the only basis of performance evaluation, particularly if subjects may be motivated to present themselves better than they actually are. Especially in case of frequent behavior, like navigation behavior, people usually do not remember and consider all relevant actions (here all previous navigation situations). In addition, people may not be able to clearly define what kinds of behavior have to be included into the category navigation. Is it easier to evaluate one's performance at a specific task or general navigation performance?

The navigation situations that subjects remember and use as a basis for self-evaluation are likely to be selective. Those navigation performances that fit the general concept of their spatial abilities may be rather reactivated and used for the self-report than navigation performances which do not fit into the concept and whose reasons are therefore often attributed to external factors. More recent relevant performances should be remembered well. The question therefore is if self-evaluation changes with recent, relevant experiences.

The following example shows the importance of realistic self-evaluations of navigation abilities. If someone knows about his/her difficulties to navigate in unfamiliar areas, the person can early organize adequate navigation aids and prepare the navigation. These consequent behaviors can reduce uncertainty in the navigation situation itself and enhance quick navigation success and traffic safety of the car driver.

Popp (1987) revealed that subjective and objective evaluations of car drivers' orientation and navigation in foreign cities differ tremendously. Whereas 88% of the interviewed subjects, asked about their last trip to a foreign city, said that they had no difficulties at using navigational aids, more than half of the observed subjects in Popp's field study showed obvious problems with regard to route finding and driving (traffic safety).

The question is if this noticeable discrepancy between objective and subjective measures that Popp (1987) found for car drivers' orientation and navigation in foreign cities can also be found in other groups of navigators or other navigation situations, here navigating pedestrians.

Sociodemographic factors: Means of transportation

We know that the way of moving (on foot, by bike, by car, by bus, tram or subway) through an area significantly influences the acquisition of spatial information. Pedestrians and bikers may use different lanes than a car or bus. But even if they move on the same route, they are likely to perceive different things. For example, pedestrians may pay more attention to small features on the route (e.g. flowers, a beautiful door of a house), whereas car drivers may rather focus on traffic lanes and street signs. Contrary to that, subway travelers may not watch the route at all. As they do not navigate themselves, it is sufficient to know where to get out and the scenery in the tunnel is boring anyway. But what do frequent subway travelers do if they walk or go by car? Do they continue to rely on others (like the subway user) as much as they can? Do they lack the navigation experience frequent bikers or car drivers gain when moving around? The resulting question is if the habit of moving through the environment in a certain way (e.g. usually to take the subway) influences the acquisition of spatial knowledge in an experimental navigation situation even if all subjects move in the same, specific way, they walk.

3.1.3 Dependent and independent variables

The independent variables are:

- type of route description: landmark-based vs. route sequences
- route sequence: first maypole, then statue or first statue, then maypole
- previous navigation experience in different fields of life (profession, hobbies)
- route familiarity: route of the subject's neighborhood vs. newly trained route
- navigation aid used (memory of route vs. another person's route description vs. memory and own route description)
- navigation environment: R vs. VR
- gender

The dependent variables are:

- navigation performance: success, time, route
- elements used for route description
- number of crucial and redundant sequences in subject's route description
- route description quality
- direction estimation accuracy
- subject's evaluation of own direction estimation
- strategies at direction estimations
- details (landmarks and routes) marked on maps that indicate just paths and buildings of the experimental terrain
- self evaluation of subject's own navigation abilities

3.1.4 Subjects

40 Adults (19 male, 21 female) participated in the experiment.

To find these persons, notes were put up at supermarkets, subway stations and other places where many people come together. Also newspaper advertisements in the local newspaper were set up. In the notes and advertisements, people were not told what the experiment deals with. People were only receiving the information that the Faculty of Aerospace Technologies was looking for test subjects for a scientific study. Subjects got paid for participation.

The test subject had to be between 25 - 55 years. We chose that age group because people under the age of 20 are still developing spatial cognition ability (Witkin, Goodenough & Karp, 1967), people between 20 and 25 years represent the typical student population and people older than about 55 years gradually “return to field dependence” (Comalli, 1965; Schwartz & Karp, 1967). Therefore the age group 25-55 years is a sample with a steady level in both aspects. The test subject should not have been on this campus before.

In order to control for sociodemographic factors (e.g. age, education, previous navigation experience), subjects had to fill in a questionnaire.

Subjects are divided into four subgroups and run through the experiment individually. They don’t know about the ensuing tasks or the aim of the experiment. After the experiment, they get an explanation of its goals.

3.1.5 Design

At the second experiment, subjects rate their own navigation abilities, give route descriptions of a familiar route and a route they get to know on a guided tour, navigate with a standardized route description (standard route description made by the research team) and on another route with their own route description, estimate directions, and finally mark these routes and perceived landmarks on maps.

A map of the campus with both routes and the main landmarks indicated can be found in Chapter 3.1.7.

The experiment consists of eight parts, three walks and five other tasks.

As for the walks, we set up four different experimental conditions (groups A,B,C, and D). The tasks were principally the same for all subjects. The permuted experimental tasks are presented below in Table 13.

At the first walk, the test subject is led by the instructor (guided tour) from the starting point to the maypole (groups A and B) or to the statue (C, D).

At the second walk, the test subject has to find the way from the start to the statue/maypole with a standardized route description based either on landmarks (A, C) or on route sequences (B, C).

The third walk of the experiment takes place in virtual reality (described in Chapter 1.10.2). Here, the test subject has to find the goal of the first walk with the help of his/her own route description.

The design is A*B(*V), i.e. A represents the goal of the first walk, B represents the navigation help of the second walk, and C the subjects' characteristics.

Task \ Group	**A**	**B**	**C**	**D**
R: goal of first walk	maypole	maypole	statue	statue
navigation aid	guided tour	guided tour	guided tour	guided tour
R: goal of second walk	statue	statue	maypole	maypole
navigation aid	standard route description based on landmarks	standard route description based on route sequences	standard route description based on landmarks	standard route description based on route sequences
VR: goal of third walk	maypole	maypole	statue	statue
navigation aid	memory and own route description	memory and own route description	memory and own route description	memory and own route description

Table 13: Experimental design

3.1.6 Hypothetical assumptions

Route description classes and success

In the first experiment, subjects remembered a interindividually different selection of spatial information and used a different combination of navigation strategies. When asked to describe the route, the description should also be based on the subject's knowledge about this route. Which of the available pieces of information the subject uses to describe the route and how he/she presents it to the hearer probably further depends on his/her abilities and preferences and the ascribed hearer's abilities.

Route descriptions and navigation strategies are related: route descriptions provide information in using the corresponding navigation strategies.

In the first experiment, some navigation strategies were more likely to lead to success than others (or were rather used by successful navigators), but various strategies lead to success. Thus, the first experiment shows that there are many different ways (i.e. navigation strategies) to reach a goal successfully.
I suppose that likewise, there may be also many different ways to describe the route to a goal successfully.

Effects of route familiarity on route descriptions
When getting to know a new area, people develop particularly landmark knowledge. With further spatial experiences in this area, i.e. with increasing familiarity, the dominance of spatial knowledge is shifted to route and later to survey knowledge (see Chapter 1.6.3).
According to these stages of dominant spatial knowledge, I expect a dominance of landmark related components for unfamiliar routes, whereas in descriptions of familiar routes, there should be significantly more route sequences.

Route descriptions based on landmarks or route sequences
Landmarks have a variety of useful functions for navigation (see Chapter 1.4) and can be combined with spatial actions to carry out at the specific landmark, but have to be well described so that they can be recognized by the navigator. Route sequences also provide the information where to act, namely to turn right or left at a certain junction. This junction and the way of counting off-going streets towards it has to be described precisely, because the navigator has to count the junctions which offers various error opportunities.
Thus, both landmarks and junctions have to be described well in order to be useful for the navigator who does not dispose of the speaker's implicit knowledge. Thereby people are probably more likely to further describe a landmark than to describe the counting rules.
In addition, the advantage of a recognized landmark to a recognized junction is that a landmark can additionally confirm to be on the correct route. Once the landmark is recognized unequivocally, the navigator can usually be quite sure to be on the right track and move on quickly, whereas the navigator counting the junctions may remain

uncertain about the route and therefore spend more time thinking about the decision points and about each off-going street.
Therefore, I suppose that route descriptions based on landmarks enable subjects to significantly faster navigation on both routes than route descriptions based on route sequences.

Direction estimation

As navigation success and the use of direction as navigation strategy were clearly related in the first experiment, I expect successful navigators to make significantly better direction estimations than unsuccessful navigators.
Furthermore, subjects are asked to estimate the direction of three locations that are not visible from the present position. I expect significantly better estimations for the start, compared to the other two positions (route’s goal and office), because subjects have walked on the route connecting actual position and start, but not on the routes directly connecting the actual position to the other two points.

Map task

Navigation aids and its components direct the navigators’ attention and thereby the cues perceived and integrated during navigation, i.e. if the route description consists of landmarks, navigators focus on landmarks, because they search for landmarks in order to find the continuation of the route. Therefore, I suppose that after navigation, subjects remember especially the cues they focused on during navigation. Now if route description and thereby navigation are based on landmarks and subjects focus on landmarks during navigation, these subjects are expected to remember more landmarks. If route description and thereby navigation are based on route sequences, those subjects are expected to remember more route sequences.
In the last task, the so-called map task, subjects have to mark remembered routes and landmarks on a map of the experimental area. I expect the groups that were navigating with the route description based on landmarks (and who supposedly rather focus on landmarks) to mark significantly more landmarks on the two maps in question than subjects who were navigating with the route description based on route sequences.

Self evaluation

The experiment provides recent navigational experiences that constitute an additional basis for subjects' self evaluation. Therefore, the second self evaluation (at the end of the experiment) should correlate on a higher level than the first evaluation (at the beginning of the experiment) with recent objective measures, i.e. navigation performance and estimations given during the experiment.

Compared to the general evaluation of one's abilities which might be difficult to evaluate (various performances are to be evaluated and there is usually no clear definition which performances have to be included), the evaluation of a specific (clearly defined) and recent (well remembered) performance, here direction estimation performance, should be easier in my opinion. Therefore, a higher correspondence between evaluation and objective performance is expected for the performance evaluation of a specific task (compared to general navigation performance). Of course, there may be also abilities that are easier to rate in general than in a specific situation and there may be interindividual differences with regard to self-evaluation abilities in different situations.

Gender differences

I expect especially women's evaluations to increase after successful navigation during the experiment (see Table 14). I further suppose that men are more self-confident with regard to navigation performance (see also Quaiser-Pohl, 1998). No matter if this confidence results from actual performance experiences or from common expectations (a man is usually good at navigation), it should lead to high self-evaluation with regard to navigation in general and more specifically, with regard to direction estimation performance. Therefore, I expect men to be more self-confident of their navigation abilities and of their direction estimations.

	First self-evaluation (before the experiment)	Second self-evaluation (after the experiment)
Men	+	+
Women	-	+

Table 14: Expected self-evaluations of navigation abilities before and after the experiment (according to gender)

Navigation exercise

I suppose that more exercise in orientation and navigation enables subjects to better navigation performances.

3.1.7 Route

Two different routes were chosen for this experiment. Figure 17 shows the experimental area, the eastern part of the university terrain, with both routes, starting and respective final points, and a few landmarks.

The route to the maypole is the same used in the first experiment (route 1), leading to the northeastern corner of the campus. The second route (route 2) has the same starting point, but leads to the southeastern corner. Both routes feature about the same length, their beeline directions (direct connection between starting point and goal) differ by about 50°. After the divergence at the first crossroads, both routes run approximately parallel to each other. The second route was selected so that both routes do not cross, even if a subjects deviates from his/her itinerary. Besides, the straight lane ("Werner-Heisenberg-Weg") featuring a broad view was avoided, because from there subjects would gain a survey of a large part of the campus and both routes.

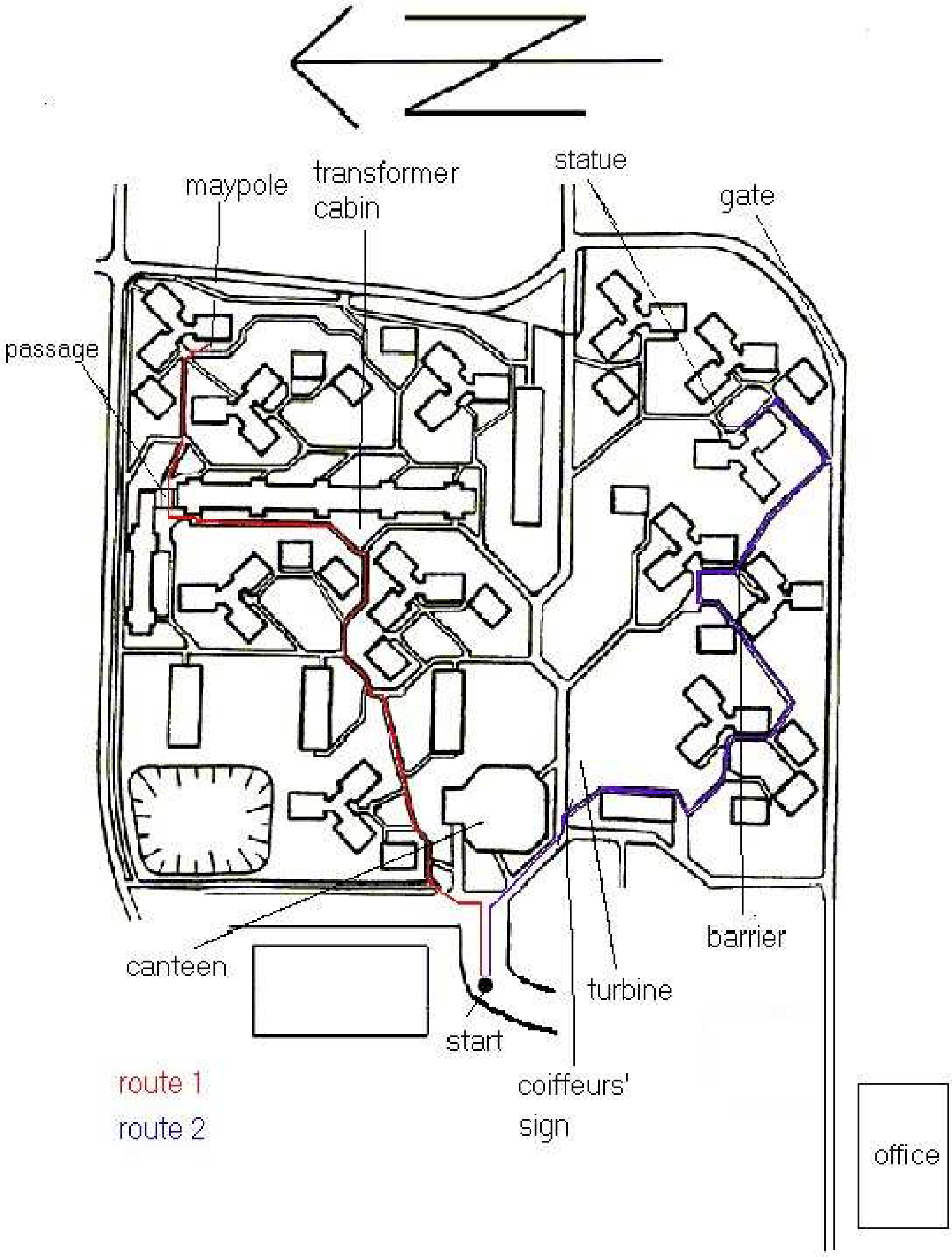

Figure 17: Campus map with routes and selective landmarks

3.1.8 Sequence of events and description of experimental tasks

The test subject is picked up at the local subway station or at the car park by an assistant and brought to the office by car. At the office, the experimenter welcomes the subject.

1. Rating of the subject's orientation and navigation abilities

   The experiment begins with a rating of the subject's orientation and navigation abilities by the subject him/herself and by his/her fellow men on a five-point rating scale.

2. Route description in the subject's neighborhood

   The second task is to describe a route in the subject's neighborhood, e.g. the way from the subject's home to the next supermarket.

3. First walk: Training phase with subsequent route description

   Afterwards, the subject is brought to the starting point by car. I decided to take the car in order to distinguish the transfer route clearly from the experimental route and to avoid the subject receiving further information about the campus at that time.

   The starting point, marked with a dot on the map (see Figure 17), is the same for all four groups. From here the instructor leads the subject either to the maypole (A, B) or to the statue (C, D), so that the subject is able to concentrate on the environment. The experimenters were instructed to avoid long conversations with the subject and to prevent other potentially disturbing events.

   The experimental subject is told at the start that after the walk, he/she will have to write a route description from the starting point to the goal (maypole/statue). I decided to do so in order to avoid different levels of information concerning this task's aim (between subjects supposing that the next task will be to produce another route description and subjects who have no idea about the task's aim or suppose other aims). However, it has to be considered that the announcement of the following task (to produce a route description) influences the subject's focus of attention and that this situation may differ from spontaneous route descriptions given in everyday life.

After having reached the aim, the test subject and the instructor are taken back to the office by car.
Back at the office, the subject is instructed to write down a route description of the first walk with free choice of presentation manner, i.e. subjects can write sentences or notes or draw a map of the route to be described on a piece of paper (DIN A4).

4. <u>Second walk: Navigation with standardized route description</u>
Thereafter, the test subject is brought back to the starting point again. For the second walk on the campus, the subject is handed a standardized route description, either with landmarks or itinerary (route sequences). The test subject's task now is to find the new aim (statue if subject has been to the maypole at first walk/ maypole if subject has been to the statue at first walk) with the help of the information in the standardized route description.
The first experiment showed that even within one area or culture, a variety of names exists for the very same object. Often these descriptions characterize very different things and thereby evoke totally different imaginations of the real object which may not enable the hearer to recognize the described landmark.
Likewise successful usage of route sequences requires the agreements of speaker and hearer about its definitions. For example, the hearer needs to know what is considered a street if he/she has to make a turn at the third street. The hearer may pass a small lane reserved for pedestrians and bikers and probably does not know if the speaker counted this lane or not.
For those reasons and in order to check if a well prepared definition of junction enables different subjects to find a route, I decided to provide a good definition of junction (we showed them photos of junctions and non-junctions to train them to differentiate) along with the route description based on route sequences, so that subjects get a chance to learn when the described sequences are to be applied.
The standardized description was created by the researchers and tested in pilot studies. There are two versions for both routes: one version is based on landmarks and includes just landmarks and the related actions, the other version is based on route sequences and includes only one additional distance indication;

Each subject receives one of the four standardized descriptions according to his/her experimental group.

5. Direction estimation

Having reached the aim, the test subject is asked for three direction estimations via a disc equipped with an arrow (see Figures 18 and 19): to the office, starting point and goal of the first route; additional questions given to the subject are, what strategy did the person use to estimate the directions and how sure is he/she about his/her estimations.

Having done this, the test subject and the instructor are taken back to the office by car.

Figure 18: Direction estimation device: disk equipped with an arrow to indicate the chosen direction

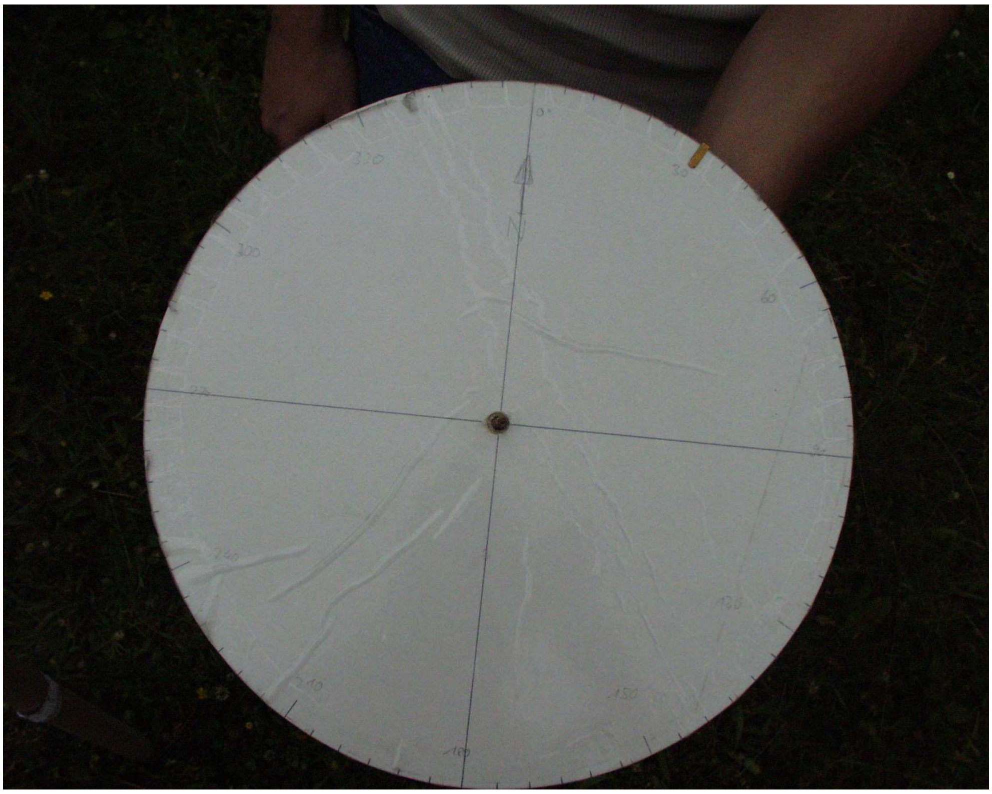

Figure 19: direction estimation device: disk with degree scale from below

6. <u>Third walk: Navigation to the first walk's goal in virtual reality with own route description</u>

Back to the office, the test subject is taken to the vision dome, where the virtual reality part is taking place. At the third walk, the task is to find the way to the first aim (walk led by instructor) with the help of his/her self-made route description. The instructor operates the mouse which triggers the movements in VR. At each junction the instructor asks the test subject where he/she wants to go and why he/she decides to use that way.

In pilot experiments, I noticed that many subjects have difficulties to train the operation of the mouse and to pay attention to the route at the same time. In order to avoid interindividually different conditions, I decided to have the experimenter operate the mouse according to the subject's instructions.

7. Questionnaire

Before coming to the last part of the experiment, the test subject is asked to fill in a questionnaire. The content of the questionnaire consists of 19 questions based on the experiment itself, education and occupation, means of transportation used, living, experience in navigation and personal interests.

8. Map tasks

The last task is to mark the two routes on structural maps of the campus (see Figure 31). The subject is handed four identical maps, one after another. Two maps are provided for the first route (guided tour with subsequent route description production and later navigation – third walk) and the other two for the second route (navigation with standardized route description).

On every first map, the test subject has to mark first the route and then the remembered landmarks from memory. On the following map, he/she has to mark the route with the opportunity to use the self-made/ standardized route description and several landmarks given by the experimenter.

Table 15 gives an overview of the sequence of map tasks.

Map number	**Route to be marked**	**Aid**
1.	First and third walk	None
2.	First and third walk	subject's route description
3.	Second walk	None
4.	Second walk	standardized route description

Table 15: Sequence of map tasks

3.1.9 Data recording

During both training and test phases, the duration of the walks is recorded (in reality by stopwatch, in virtual reality by computer). In addition, during the two navigation tasks, the chosen route is registered by computer in VR and by the experimenter marking chosen paths and turns on a map of the terrain in R.

The route description in the subject's neighborhood is registered with a dictaphone. Subjects write or draw the route description of the training route on a piece of paper (DIN A4).

Direction estimations are carried out by means of a disc (35cm in diameter), equipped with an arrow. The disc is screwed into a wooden pole that remains at the site (see Figure 18). Subjects are asked to align the arrow so that the arrowhead points into the direction of the respective aiming point. The compass scale is located on the bottom side of the disc, so that subjects cannot use it as an aid. The experimenter notes the degree of the direction indicated. I decided to use this disc in order to avoid angle measurement errors that might occur when using the direction of the subject's straight arm instead of the unknown line of sight.

Sociodemographic information and previous navigational experiences are collected with a short questionnaire that subjects have to fill in.

Possibly influencing factors, such as weather conditions, subjects' motivation, etc. are noted, as well.

3.10 Data preparation

Before presenting the results, I will explain the analysis of composition and quality of route descriptions.

3.10.1 Textual analysis of route descriptions

Subjects' route descriptions are analyzed with regard to the content classes
in order to investigate

- the composition of subjects' route descriptions,
- the frequency of usage of the various classes of route description components,
- if there are combination preferences for the classes (are there classes that are often used together in one route description?),
- if there is any coherence between route description classes and quality measures, and
- the correspondence of route description classes and navigation strategies.

There are many different ways to analyze and classify the components of route descriptions. I decided to use both a previous approach from the literature (Denis, 1996, described in Chapter 1.8) and the experiences from the first experiment (described in Chapter 2.3) and integrate them into a new classification. As Denis' schema focuses on landmarks which are doubtlessly an important, but not the only component of route descriptions, I completed my classification with components found at the elicitation of navigation strategies at the first experiment (e.g. route sequences, direction). I distinguish local cues (information about one sequence) and global cues (information about the route/area that can be used at various sequences), both comprising several classes of route description components. These classes are complete and exhaustive.

Local cues

1. Distances referring to consecutive sequences
   Distance information in meters or time indicating the distance from the present position to the next action guideline;
   Example: Turn left at the small lane after about 50 meters from here!
2. Exclusion principle referring to landmarks
   Instructions not to go in direction of a specific landmark;
   Example: Don't cross the Rhine bridge!
3. Route sequences
   Route knowledge consists of the familiar routes connecting junctions and/or landmarks and features a sequential structure. The sequence of landmarks and turnings is used to proceed on the entire route. Itineraries are described which indicate what to do at the next decision point;
   Example: Turn right at the first street branching off, then turn left at the third crossroads!
4. Landmarks

4.1 Introduction and description of landmarks
   Beyond just mentioning a landmark in the route description, the landmark's features are further described – probably in order to facilitate its recognition;
   Example: There is a high, yellow painted house with wooden windows.

4.2 Action guideline with landmark reference
   Indication where (at a specific landmark) to do what (go straight, turn right/left), so the decision point is described by a landmark and the spatial action indicated at that point is added;
   Example: Turn right at the Safeway Supermarket!

4.3 Path character

Path texture is an important landmark that can be recognized visually, but also based on auditory (e.g. sounds evoking when moving on the path) and motor (when walking or driving on a path, we can feel e.g. irregularities of the path's covering) senses.

Example: First follow the brown path, then the cobblestone pavement!

4.4 Street names and building numbers

A specific street or building are indicated;

Example: Take the university street, look for building number 18 on your right hand side!

Global cues

5. Direction

Indication of beeline direction from present position to the goal;

Example: The goal is located in a direction obliquely to the left of the green house.

Sketch maps are also included here, because they indicate the direction from one object to another and give a survey of the structure of the area;

6. Exclusion principle referring to districts

Instructions not to go to a certain district (increasing the distance to the goal or just not encompassing the goal) or not to leave a district (that encompasses the goal);

3.10.2 Crucial sequences

The first experiment shows that there are many different ways (i.e. navigation strategies) to reach a goal successfully and I suppose that likewise, there may be also many different ways to describe the route to a goal successfully. Therefore, I need a criterion that can evaluate the whole variety of ways to describe a route. Operationally defined, successful description means that the statement describes the sequence in a way so that the hearer can take the correct continuation of the route.

I analyzed both routes to decide which are the route's crucial sequences, i.e. important decision points that can be passed only with the relevant cues. The maypole-route is composed of nine, the statue-route is composed of eleven crucial

sequences. Now, in order to determine the route descriptions' quality, I can check if route descriptions include all definitively necessary, i.e. crucial sequences. Additional statements are considered redundant, which means here that these statements provide information that is already included in the crucial statements.
The criterion "existence of the crucial sequences" allows one to evaluate the whole range of route descriptions according to a meaningful criterion, namely its completeness of comprehensible instructions for each decision point.
Sketch maps can be analyzed based on the same criterion. Therefore, it is an advantage of this evaluation criterion that the variety of possible statements to describe a certain decision point can be taken into account.
In order to consider the differing number of crucial sequences for both routes, one route description quality criterion is constituted by the ratio of described crucial sequences to the necessary number of crucial sequences. This ratio is called Information Content (IC) and indicates the percentage of crucial route sequences in a route description (maximum is 1 or 100%). The remaining sequences (100%-IC) are not described at all, they are not described comprehensibly, or they are redundant.

3.10.3 Redundant sequences

As described in the previous section, non-crucial statements will be called redundant sequences here. Redundant statements can be additional descriptions, e.g. "turn left at the green house" (crucial sequence). If there was only one green house, the further description, e.g. "it has 3 stories, wooden windows and lots of flowers on the balcony", would be redundant as the house can be recognized due to its color. Redundant sequences may also describe the route in between decision points, i.e. at parts of the route where a description is not essential, because the navigator just follows the street or path to the next described decision point. Sometimes one crucial section is described twice, e.g. "you have to continue the street to the second crossing street where you turn left, so you turn left at the green house". If it is unequivocal which one is the second street or the (only one) green house, the other statement can be considered redundant.
Like this, a route description can be analyzed with regard to its crucial and additional or redundant statements. To what extent redundant statements or sequences may be useful in different situations is discussed in Chapter 3.3.1.1. Again, in order to

consider the differing number of crucial sequences for both routes, the ratio of redundant sequences to the number of crucial sequences (within one route and one subject) constitutes the Redundant/Crucial sequences ratio (RC).

3.10.4 Expert rating

In addition to the crucial sequences and the consequential IC, two experts, knowing about the route and its features, evaluated all of the route descriptions subjectively on a 5 point rating scale ranging from 1 (very good) to 5 (useless). Criteria were comprehensibility, clearness and usefulness of the route description as a whole. The interrater reliability is expressed by the intraclass correlation coefficient which is .84 (here the correlation as there are two ratings to be compared, Bortz, 1995).

3.2 Results

T-tests results are generally two-sided, unless otherwise indicated.
Regarding correlations, the coefficient of determination, i.e. the shared variance of two correlated variables, is indicated by r^2.
The effect size d considers both the difference between the mean values of the compared groups and the standard deviation of the measured variable. The consideration of the standard deviation in addition to the mean difference helps to evaluate the practical importance of the difference between the two mean values. The same difference may be of high importance in case of a small standard deviation and of low importance in case of a high standard deviation. The effect sizes of the t-test for independent variables can be classified into small, medium and large effects according to the table below (Bortz & Döring, 1995).

effect size classification	small	medium	large
D	0.20	0.50	0.80

Table 16: Effect size classification

3.2.1 Route descriptions

3.2.1.1 Number of statements and classes per route description

First of all, I describe the total number of statements made by one subject and the number of different (component) classes used by one subject.

On average, subjects made eleven statements ($\bar{x}$=11.28, σ=5.5) in their route descriptions of the maypole or statue-route.

These statements used within one route description can be classified (on average) into four classes ($\bar{x}$=4, σ=1.8). The different classes of statements within one route description are described in Chapter 3.10.1.

3.2.1.2 Crucial sequences

On average, the total number of route description statements corresponds approximately to the total number of crucial sequences ($\bar{x}_{\text{(number of statements per route description)}}$=11.15, σ=5.3, number of crucial sequences:11) for the statue-route, but not for the maypole-route. Although the maypole-route has two crucial sequences less (nine crucial sequences), the total number of statements is about the same than at the statue route ($\bar{x}_{\text{(number of statements per route description)}}$=11.42, σ=5.9).

But are these statements describing the crucial sequences?

This is measured by the quality criterion Information Content (IC) which is constituted by the ratio of described crucial sequences to the necessary number of crucial sequences. It considers the differing number of crucial sequences for both routes and indicates the percentage of crucial route sequences in a route description.

Only five subjects (13%) manage to describe all crucial sequences. The average number of described crucial sequences is six for both routes, which corresponds to the number of chunks (7 +- 2 chunks) people are usually able to remember (Miller, 1956).

As the number of crucial sequences differs between the routes (nine crucial sequences at the maypole-route and eleven at the statue-route), the same number of described crucial sequences leads to better information content at the maypole route (six out of nine sequences were described) than at the statue route (where six out of eleven sequences were described). The average IC is .68 for the maypole-route (σ=.24) and .53 for the statue-route (σ=.23), i.e. 68% of the crucial route sequences are described at the maypole-route and 53% are described at the statue-route, which contains two more crucial sequences. Hence, route descriptions for the maypole-route include significantly more of the relatively expected crucial sequences (t-test comparing the IC of both routes, df=37, p=.047, r^2=13%, d=.65), i.e. maypole-route descriptions are more complete than route descriptions for the statue-route.

However, better evaluation of the maypole route is not confirmed by expert evaluation (general rating by two experts).
Eight subjects produced sketch maps (three of them additionally) to describe the route. These were analyzed based on the same criterion (IC).

Correlations show that the time used to produce one's route descriptions increases first and foremost with the total number of statements (r=.625, p<.001), but also with the number of classes (r=.374, p=.017) per subject. Thus, subjects taking more time to write their route description do not generally take more time thinking about it, but produce more statements and therefore have the chance to use more different classes of components.

<u>3.2.1.3 Redundant sequences</u>
Non-crucial statements are called redundant sequences here. The average ratio of redundant sequences to the number of crucial sequences constitutes, i.e. the average Redundant/Crucial sequences ratio (RC) is .93. This means that on average, subjects use about the same number of crucial and redundant sequences to describe a route.
Differentiating for both routes, the average RC is .68 for the maypole-route (4 redundant sequences to 6 crucial sequences) and 1.17 for the statue-route (7 redundant sequences to 6 crucial sequences). The route descriptions for the statue-route contain relatively more redundant sequences compared to the maypole-route. This difference is not statistically significant.
Correlations between route description production time and the RC ratio (r=.48, p=.002, r^2=.23, i.e. 23% shared variance) show that the longer a subject takes to produce his/her route descriptions, the higher RC, i.e. the more redundant sequences are produced (relative to the number of crucial sequences). Furthermore, a relatively high number of redundant sequences correspond to longer durations of subsequent navigation. So, taking more time to describe a route does not necessarily increase the number of crucial sequences and thereby the quality.

Duration of navigation in VR correlates significantly with RC, the ratio of redundant sequences to the number of crucial sequences (r=.430, p=.006). The less redundant sequences (relative to crucial sequences) are used, the faster the goal is retrieved in VR. Navigation performance in VR does not correlate significantly with any other measure of route description quality.

3.2.1.4 Expert rating

The mean of both experts' ratings for each route description is called 'expert evaluation' in the following. Considering all route descriptions the subjects made of the first campus route they got to know, this average evaluation of both experts amounts to 2.7 (medium level). Distinguishing both routes, expert evaluation reveals better grades for the statue-route ($\bar{x}$=2.55, σ=1.04) than for the maypole-route ($\bar{x}$=2.95, σ=1.09). The difference is not significant, though.

Expert evaluation correlates significantly (r=.67, p<.001, r^2=.45) with information content (IC, indicating the ratio of described crucial sequences to the necessary number of crucial sequences). As a result, the expert evaluation and IC provide related, but not identical information and are therefore used simultaneously.

In contrast to the results of IC, the expert evaluation reveals slightly, but not significantly better results statistically for the statue-route.

The expert evaluation increases with the total number of statements (r=.50, r^2=.25) and classes (types of information provided in the statements, r=.42, r^2=.18).

3.2.1.5 Contiguity between route description quality measures and its characteristics

The following Table 17 gives an overview of significant correlations related to route descriptions.

There is neither correlation between information content nor between expert evaluation and time needed to produce the route descriptions. Relating the production time to RC (comparison of the number of redundant to the number of crucial sequences), it results that the longer subjects take to produce a route description, the more redundant sequences are produced.

Beyond its correlation with the number of redundant sequences, the route description production time correlates as well significantly with the total number of statements and classes.

Thus, taking more time to produce a route description increases the total number of statements, but it does not necessarily heighten the number of crucial sequences and thereby its quality.

Correlating variables	Correla-tion	P-value	explained variance	Tendency
Route description production time and total number of statements	.625	.000	39%	The longer someone takes to write his route description, the more statements are produced.
Route description production time and RC	.480	.002	23%	The longer someone takes to write his route description, the more redundant sequences are produced.
Route description production time and number of classes	.374	.017	14%	The longer someone takes to write his route description, the more different classes of statements are used.
Expert evaluation and total number of statements	.495	.001	25%	The higher the number of statements, the better the expert evaluation.
Expert evaluation and number of classes	.420	.008	18%	The higher the number of different classes, the better the expert evaluation.
Number of classes and total number of statements	.846	.000	72%	The higher the number of statements, the higher the number of different classes.

Table 17: Overview of significant correlations related to route descriptions

3.2.1.6 Usage of route description classes

Figure 20 shows how many subjects (percentage) used the described classes. In the following, I describe local and global cues beginning with the local cues that were used by most subjects, i.e. the description sequence follows the usage frequency as represented in Figure 20.

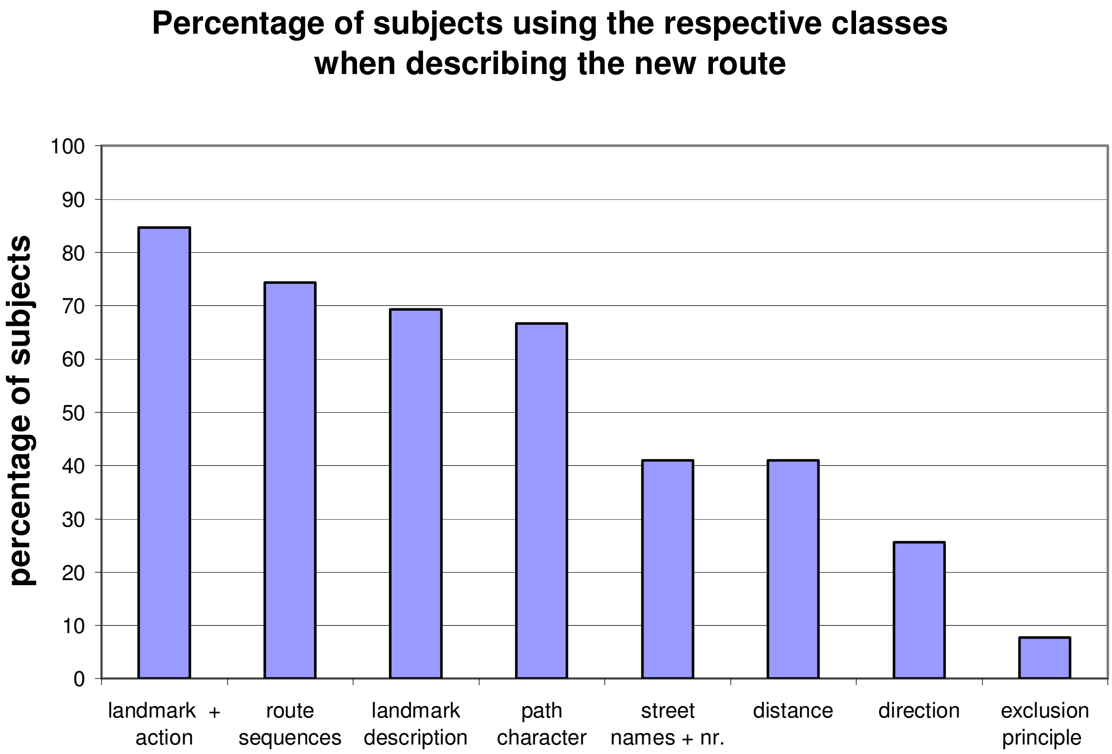

Fig. 21: Percentage of subjects who used the respective classes for their route description

The local cues dominate. **'Action guideline with landmark reference'** is the favored class that is used by 85% of subjects. Most subjects use this class three to four times within one route description. The total number of subjects' statements in one route description averages eleven ($\bar{x}$=11.28, σ=5.5).

So, if the class 'action guideline with landmark reference' constitutes (on average) three to four statements per route description (out of eleven), about one third of the route description sequences are described by this combination of landmark mention and action guideline.

Some subjects use the class 'action guideline with landmark reference' only once or twice, whereas other subjects use it for half of their statements. Anyway, these results show that 'action guideline with landmark reference' is a frequently used class of route descriptions.

The second most frequent class is **route sequences**, that is used by 74% of the subjects.

In addition to ‘action guideline with landmark reference’, there are several other, frequently used classes referring to landmarks. About half of the landmarks mentioned in route descriptions are additionally introduced and described, 69% of subjects further describe some or all of their noted landmarks. A specific kind of landmarks, the **path character**, is described quite often (by 67% of subjects). That’s why I decided to form an extra class ‘path character’ of landmark related local cues.
Street names and building numbers are used by 41% of subjects. I have to remind that on campus, unlike in most environments, this is not a very useful navigation aid, because there are only two named streets (which are used by most subjects employing this strategy) and building numbers don’t follow a logical sequence.
Besides, 41% of subjects describe **distances**, which shows that some people do indicate metric measures at first contact, but that the majority prefers other strategies at that stage.
The **exclusion principle** referring to landmarks was only used by three subjects (7.5%), one of them using it five times.
In general, landmarks play an important role for route descriptions. Summing up the total number of all landmark related statements, they account for two thirds of all statements in my subjects’ route descriptions.

Only a few subjects included global cues into their route descriptions. One fourth (25%) describe **directions** to the goal, whereas no subject delimits the area. The class ‘exclusion principle referring to districts’ was not used by subjects, probably because the route to be described is located within one district.
To sum up the route description analysis, route descriptions are mainly composed of local cues containing landmark and route information.

3.2.1.7 Analysis of combinations of route description classes

First, the uses of route description classes were correlated with each other in order to check if there are any preferences to use specific combinations of classes.
The usage of direction principle and exclusion principle correlates significantly (r=.34, p=.035). Furthermore, the usage of landmark descriptions correlates significantly with two other landmark related classes, namely the combination of landmark and action guideline (r=.34, p=.036) and the usage of street names and building numbers (r=.33,

p=.039), and with route knowledge (r=.36, p=.023). So, on the one hand, there are some statistically significant combinations of route description classes that are frequently used together.

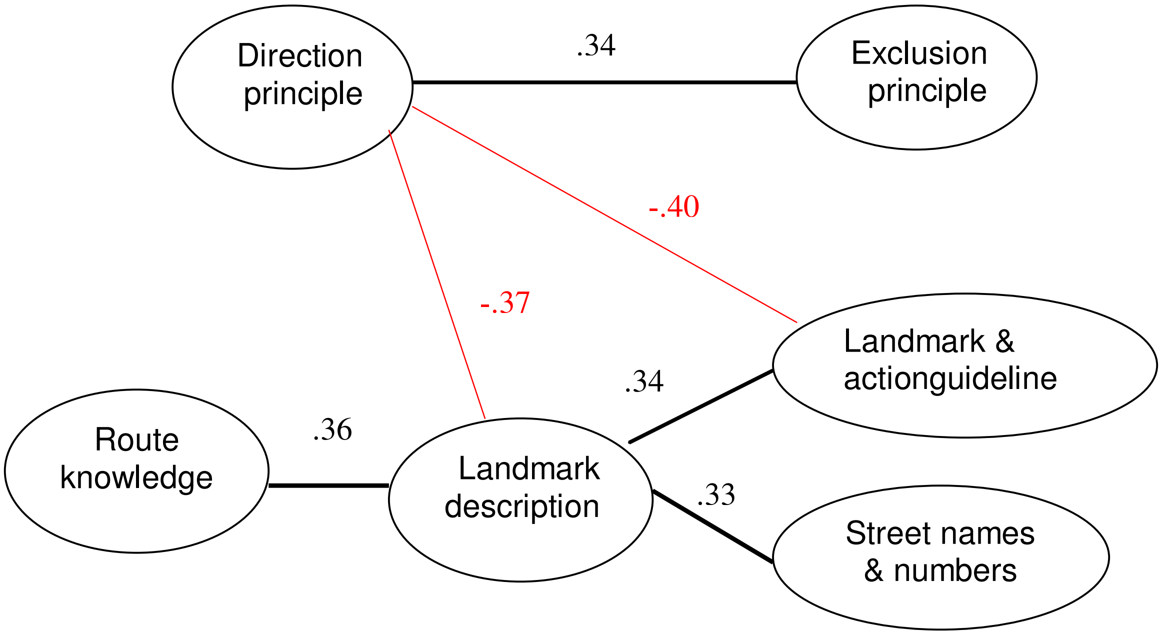

Figure 21: Correlations between the usage frequency of specific route description classes

On the other hand, there are route description classes that are rather not used together, as well. I found negative correlations between direction principle and both explicit landmark classes, that are landmark description (r=-.37, p= .020) and the combination of landmark and action guideline (r=-.40, p=.011). Thus, subjects indicating the global direction describe less landmarks.

The respective correlations are illustrated in Figure 21, the numbers on the lines indicate the correlations. The red lines indicate negative correlations.

3.2.1.8 Coherence between route description classes and quality measures

I correlated the frequencies of specific route description classes with both quality measures, expert evaluation and information content, in order to see if there is any coherence between them.

Information content (ratio of described crucial sequences to necessary number of crucial sequences) correlates significantly with the usage of two classes of route description components, namely path character (r=.39, p=.016) and exclusion principle (r=.32, p=.049).

Expert evaluation correlates significantly with four route description classes. Like information content, it correlates with path character (r=.40, p=.012) and exclusion principle (r=.34, p=.035). Moreover, expert evaluation correlates with both explicit landmark classes, landmark description (r=.41, p=.009) and landmark and action guideline (r=.54, p<.001).
Thus, there are indeed many different ways to describe the route to a goal successfully.

3.2.1.9 The effects of route familiarity on route descriptions

At the beginning of the experiment, subjects were asked to verbally describe a familiar route, e.g. the way from their home to the next supermarket, in a familiar area. Further on, subjects walked on a completely new route on our campus, afterwards they were asked to give a route description of this new route. The question is if those two route descriptions differ, i.e. if familiarity of the described route and area has an effect on the use of route description classes.
I decided to focus on the classes landmarks (including all landmark related subgroups) and route sequences, because they are the two most frequently used classes (accounting for 82% of all statements used in the experimental route descriptions for the first walked route) and represent two stages of spatial knowledge, namely landmark and route knowledge.
As expected, the familiar routes that subjects describe (e.g. from subject's home to the next supermarket) differ with regard to length and to number of decision points. As every decision point has to be described, the length of the corresponding route descriptions differs as well. Therefore, the ratio of the two main component classes, landmark related and route sequences, is calculated in order to see what kind of statements (classes) predominate.
In the case of familiar routes, the average ratio is 2.57 (σ=2.15), i.e. two and a half times more route information than landmark information is given .
In contrast to that, the ratio for unfamiliar routes is 0.78 (σ=0.74), i.e. slightly more landmark information (about 1.3 landmarks per route sequence described) is given.

According to these results, familiarity has a highly significant (t-test: df=37, p<.001, d=1.11) effect on the use of landmark related and sequenced route knowledge which confirms the hypothesis that landmark knowledge is more important at less familiar routes. According to the three stages of dominant spatial knowledge (landmark, route, and survey knowledge), I expected a dominance of landmark related components for unfamiliar routes and a dominance of route sequences in descriptions of familiar routes. These expectations are confirmed.

3.2.2 Comparisons

3.2.2.1 Comparison of route description classes (experiment II) and navigation strategies (experiment I)

The two situations, retrieving a personally trained route and following somebody else's route description, are also different with regard to the selection possibilities of navigation strategies. Personal experiences in an environment (here training on a certain route) enable the navigator to choose one or a number of individually best considered strategies, depending on what he/she focused during training. By contrast, using one strategy of a given route description enables the user to use only this strategy (in absence of other redundant descriptions or further aids) when searching for the described route.

At the following comparisons, the route is a constant factor, whereas the group of subjects differs.

To begin with the comparison of the number of different strategies used for navigation and the number of route description classes of the same route, it results that route descriptions contain a significantly (t-test, df=66, p=.008, d=.67) larger variety of classes ($\bar{x}$=4.5, σ=1.86) than navigation strategies ($\bar{x}$=3.4, σ=1.38).

Another, more content related question is, if the strategies used to navigate on a certain route correspond to the strategies provided to others, i.e. to the receiver of one's route description. Thereto, I compare the navigation strategies used in the first experiment with the strategies implied by the route descriptions at the second experiment for the same route, the maypole-route.

Several strategies occur in both experiments (see an overview in Table 18).

Strategy	Frequently used as navigation strategy in experiment I	Frequently used as route description strategy in experiment II
landmarks	X	X
house and building numbers		X
exclusion principle	X	
route knowledge		X
direction	X	X
search for the location of the goal within the area	X	
search for surroundings of the goal	X	
search for known objects	X	
distance		X

Table 18: Strategies used for navigation in experiment I and for route descriptions in experiment II

Landmarks are most often used both for navigation and in route descriptions. The relevant classes for navigation are recognition of and search for landmarks, and search for known objects. For route descriptions, these are landmark description, landmark and action guideline and path character. House and building numbers are used much more often for route descriptions than for navigation (40% vs. 9% of subjects used it). In contrast to that, the exclusion principle is much more popular as a navigation strategy (60% vs. 15%). There are two other landmark related strategies that will be analyzed separately.

Route knowledge is used more frequently for route descriptions than for navigation (75% vs. 17%), whereas direction is used slightly more often for navigation (49% vs. 40%).

There are also strategies that were used either to give route descriptions or for own navigation. Some strategies seem to be rather useful for own navigation whereas others are used only in route descriptions. Subjects in the first experiment have used the navigation strategies ‘search for the location of the goal within the area’ and 'search for surroundings of the goal'. However, these strategies are not used in order to describe the same route in the second experiment. Of course, the same applies to the navigation strategy 'search for known objects'. By contrast, distance is used only for route descriptions.

3.2.2.2 Comparison of route description strategies and navigation strategies within subjects

At the preceding comparison, the route was a constant factor, but not the group of subjects. The data of the second experiment makes it possible to investigate route descriptions and navigation strategies for the same route within the same group of subjects. At the beginning of the experiment, subjects describe a route. At the end of the experiment, subjects navigate on this route in the virtual environment.

Strategy	Percentage of subjects who used it as navigation strategy	Percentage of subjects who used it as route description strategy
Landmarks	94%	95%
Route sequences	78%	74%
Direction	23%	25%
Distance	8%	41%

Table 19: Strategies used for navigation and route descriptions in experiment II

With regard to both strategy analyses, landmarks are the most frequently used strategy. i.e. in the route description (65% of all statements, 94% of all subjects used it), and at navigation based on memory and own route description (34% of all statements, 95% of all subjects used it). To sum up, almost all subjects use landmarks both for route descriptions and for navigation (see Table 19).

The usage frequencies for the next two popular strategies correspond as well.

Route sequences is the second most frequently used strategy. It is applied by three quarters of all subjects both for route descriptions (74% of all subjects) and for navigation (78% of all subjects).

Likewise, direction to the goal is used with similar frequency for navigation (23% of all subjects) and route descriptions (25% of all subjects).

But there is also a strategy that is applied more often for route descriptions than for navigation. Although distance is used in route descriptions by 41% of subjects, only 8% use it for navigation.

3.2.2.3 The effects of navigation information provided by route descriptions

We created two kinds of route descriptions, each of them composed of mostly one class, landmarks or route sequences. Knowing the routes, it takes about seven minutes just to walk on these routes. In order to allow for short orientation breaks at decision points and one or two turnarounds, I set the time limit for successful navigation at 20'.

As with common route descriptions, once you lose the right track, your chances to get back to the route without turning around are low. As subjects in the experiment did not know the route at all, it was difficult for them to notice that they made a wrong turn, especially with the route description based on route sequences. That's why I decided to allow for one wrong turn, i.e. if the subject makes a wrong turn, continues walking and does not notice the mistake for a certain time, the experimenter tells the subject that he/she made a wrong turn and leads him/her back to the last junction on the route. This happened only very few times and was noted by the experimenter.

Actually, most subjects found their way without taking a wrong turn and all subjects found the goal within the scheduled 20' ($\bar{x}$=9'21'', σ=3'44'').

Comparing both route descriptions, the landmark version enables subjects to significantly faster navigation at the maypole-route which partly confirms my hypothesis (see Table 20). There is a superior effect of the landmark based route descriptions on navigation duration at the maypole-route (t-test: df=18, p=.007, r^2=53%, d=1.46), but not at the statue-route (t-test not significant).

Route	Statue-route		Maypole-route	
Route description based on	$\bar{x}$	σ	$\bar{x}$	σ
landmarks	9'11'	3'53''	7'24''	1'50''
route sequences	8'19''	2'5''	12'31''	4'37''

Table 20: Mean and standard deviation of navigation duration on the two different routes with two different kinds of route descriptions (four conditions)

3.2.3 Navigation in virtual reality

The last navigation task is to retrieve the first walked route in the virtual campus. Subjects could use the route description they had made from this route as additional aid to their memory of the route. 75% of all subjects are successful and find the goal after an average of 10'5'' (σ=4'43'').

3.2.3.1 Comparison of navigation performance on both routes

The comparison of navigation performance on both routes, maypole-route and statue-route, in VR shows a slightly higher success rate (80% at the maypole-route vs. 70% at the statue-route) and lower navigation durations on the maypole-route. Navigation duration on the maypole-route is slightly but not significantly shorter ($\bar{x}_{(maypole\text{-}route)}$=11'24'', $\sigma_{(maypole\text{-}route)}$=5'10'') than on the statue-route ($\bar{x}_{(statue\ route)}$=13'40'', $\sigma_{(statue\text{-}route)}$=5'31'').

3.2.3.2 Comparison of navigation performance depending on navigation aid

Comparing navigation performance within subjects depending on navigation aid, it results that a standardized route description ($\bar{x}_{navigation\ duration}$=9'21'') enables subjects to similar performance as the combination of the two navigation aids, namely subject's memory of the earlier walked route and own route description ($\bar{x}_{navigation\ duration}$=10'5'').

Furthermore, navigation performance on the maypole route at first and second experiment are compared. At the second experiment, more subjects are successful at retrieving the goal (80%) and navigate faster ($\bar{x}$=10'5'') than subjects at the first experiment (condition training in R, then test in VR), where 54% retrieve the goal after an average of 17'33''.

3.2.4 Direction estimation

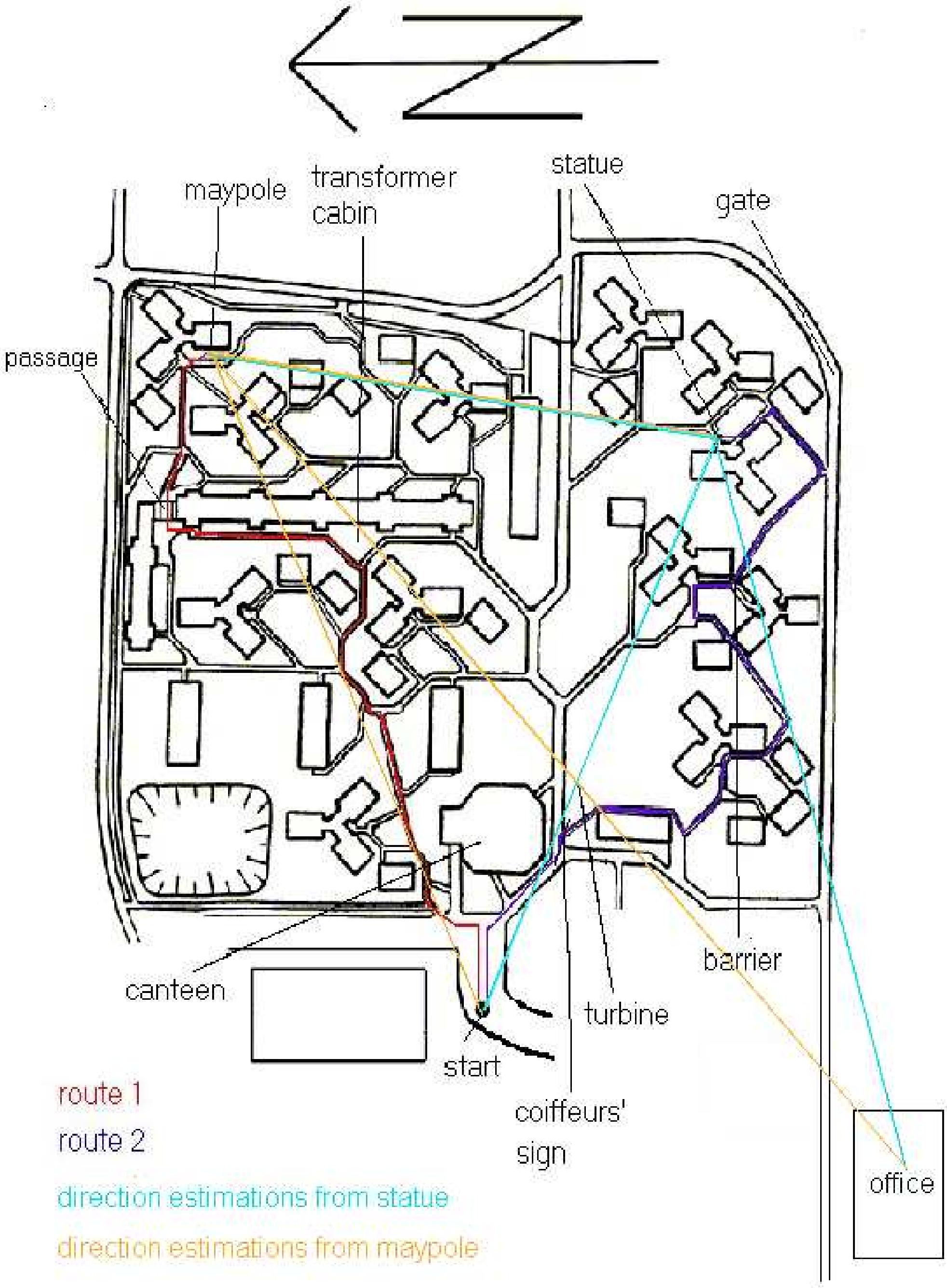

Figure 22: map of the campus, indicated are maypole-route (route 1) and statue-route (route 2) and the correct direction estimations from both goals

After having reached the goal of the second navigation, subjects have to estimate three directions from there: to the start, to the first walked route's goal, and to the office.

Half of subjects search for the maypole at the second navigation, whereas the other half search for the statue. Thus direction estimations are made from two starting points, either from the maypole or from the statue. The first walked route's goal is always the other goal, i.e. subjects at the maypole estimate the direction to the statue and inversely. Figure 22 shows both routes and the correct direction estimations from both goals.

Deviations from the correct direction are defined negatively if they are clockwise and positively if they are counter clockwise. The positive and negative misalignments are described in Chapter 3.2.4.2. In the following Chapter 3.2.4.1 and unless otherwise indicated, results are based on the absolute value of a subject's direction estimation deviation from the correct direction, i.e. the maximum deviation is 180°.

3.2.4.1 Direction estimation accuracy

The question was with which accuracy are subjects able to estimate directions in a relatively unfamiliar environment. Thus, the focus of this chapter are subjects' direction estimation performances depending on starting point and goal of estimations.

Tables 21 and 22 provide the means and standard deviations for direction estimations from both estimation positions, maypole and statue, and show that direction estimation performance does not differ with regard to the estimation position. T-tests comparing direction estimation performance from both positions (maypole and statue) do not reveal significant differences for any of the three estimation goals start, office, and statue or maypole). Figures 24 to 29 show the degrees of deviation for the single subjects in all direction estimations.

Comparing direction estimation performance with regard to the three goals of estimation, Table 23 summarizes direction estimations from both positions to all three direction estimations. The start is estimated significantly better than the two other points (t-test for dependent samples, $df=39$, $p<.01$ for comparisons between estimations to the start and the respective other point, office and maypole/statue).

Point to estimate	**Start**	**Office**	**Statue**	**Average of all 3 points**
Mean	32°	46.1°	53.3°	43°
Standard deviation	42°	38.7°	45.6°	51.7°
Percentage of deviations ≤30°	75%	40%	40%	52%

Table 21: Means and standard deviations for all three direction estimations from the maypole

Point to estimate	**Start**	**Office**	**Maypole**	**Average of all 3 points**
Mean	27.1°	47.4°	45.6°	40.1°
Standard deviation	21°	43.7°	28°	39.6°
Percentage of deviations ≤30°	65%	50%	30%	48%

Table 22: Means and standard deviations for all three direction estimations from the statue

Point to estimate	**Start**	**Office**	**Statue or Maypole**	**Average of all 3 points**
Mean	29.5°	46.7°	49.4°	41.5°
Standard deviation	32.9°	40.7°	37.6°	45.6°
Percentage of deviations ≤30°	70%	45%	35%	50%

Table 23: Means and standard deviations for all three direction estimations from both positions, maypole and statue

Sellen (1998) showed that subjects who have been living in an area are able to estimate directions with an average deviation of 11°. As subjects in my experiment were completely unfamiliar to the experimental environment, an estimation with a deviation of up to 30° is considered good. This accuracy would be still sufficient to decide on the right way at a right-angled four-way crossroads (assuming that a crossroads can be divided into four sectors of 90° and that a decision for a way can be made if the estimated direction is within this sector, i.e. 45° to the right or to the left of the path).

According to the 30° criterion, 70% of subjects did well at the start estimation, 45% at the office and 35% at the estimation of the other route's goal.

Direction estimations to the start and to the office correlate significantly (r=.49, p=.001, 24% shared variance), i.e. subjects who are good at estimating the start are likely to do a good job at estimating the office, as well, and the other way around. Direction estimation performance to the maypole/statue is not related (significantly) to the two estimations to the start and to the office.

3.2.4.2 Positive and negative misalignment

Subjects' estimations from the maypole do not deviate systematically positively or negatively from the correct estimation (see Figures 24, 26, 28). The estimations form a one peak distribution around the correct direction estimation.

This does not apply to the group of subjects who stand at the statue and estimate the maypole (see Figure 29) and start (see Figure 25). They estimate the maypole straight to the north and thereby omit the slight eastern component of the connection statue to maypole. So, 88% of these subjects deviate positively, i.e. they straighten the angle so that the maypole is estimated to be directly north of the statue (see Figure 23, green line). Then the line between statue and maypole would form a right angle with the delimiting street south of the campus.

Estimations from the statue tend to straighten the angles both when estimating the maypole (see Figure 29) straight to the north (omitting the slight eastern component) and when estimating the start (see Figure 25) straight to the west (63% of subjects omit the northern component, see Figure 23, pink line). Estimations to start and maypole form approximately a right angle.

To sum up, direction estimations from the maypole do not deviate systematically from the correct estimation, whereas there are straightening effects at two out of three statue based estimations.

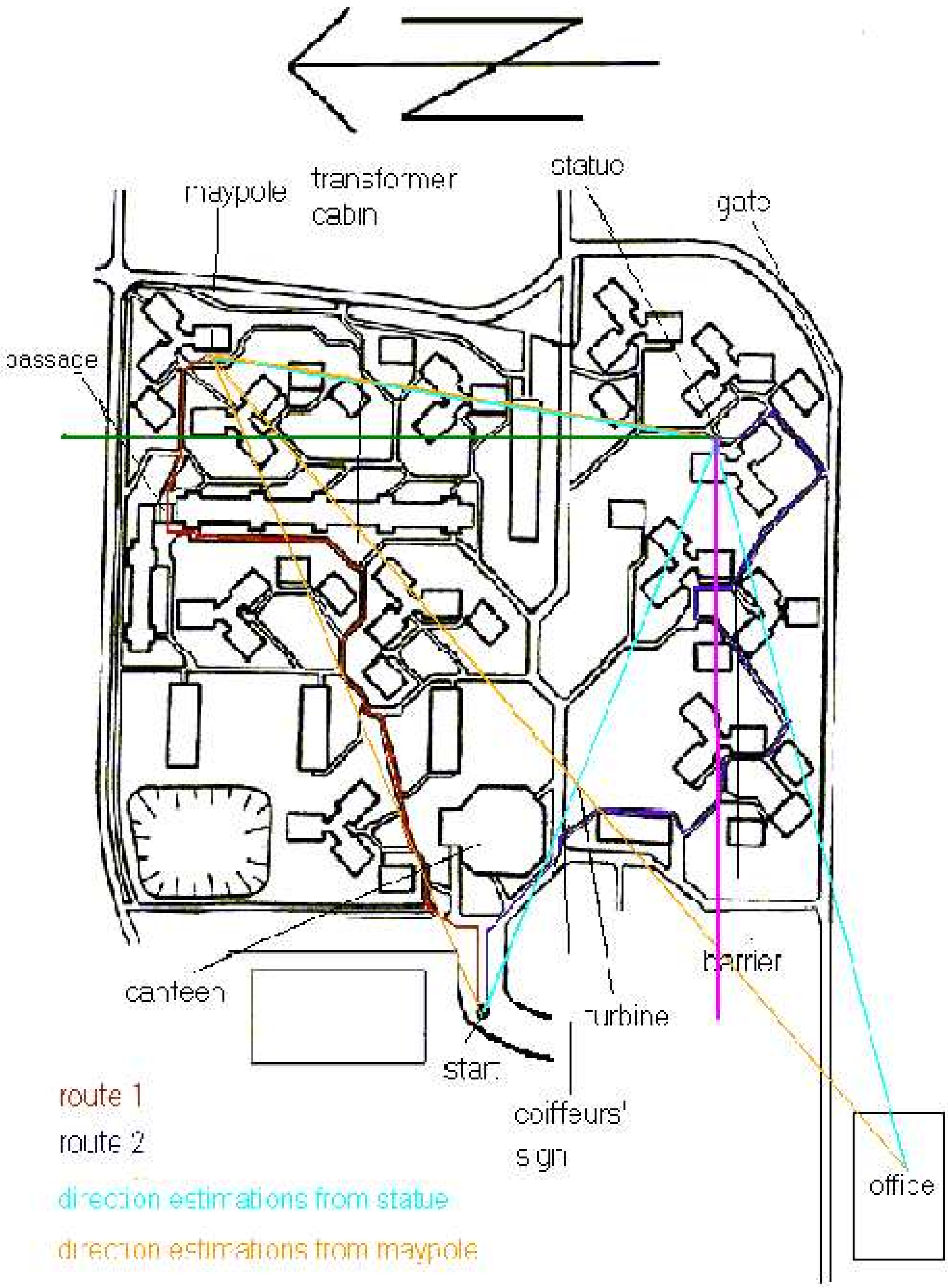

Figure 23: map of the campus, indicated are maypole-route (route 1) and statue-route (route 2), the correct direction estimations from both goals, and the systematically deviated direction estimations (by subjects) from statue to start (pink line) and to maypole (green line)

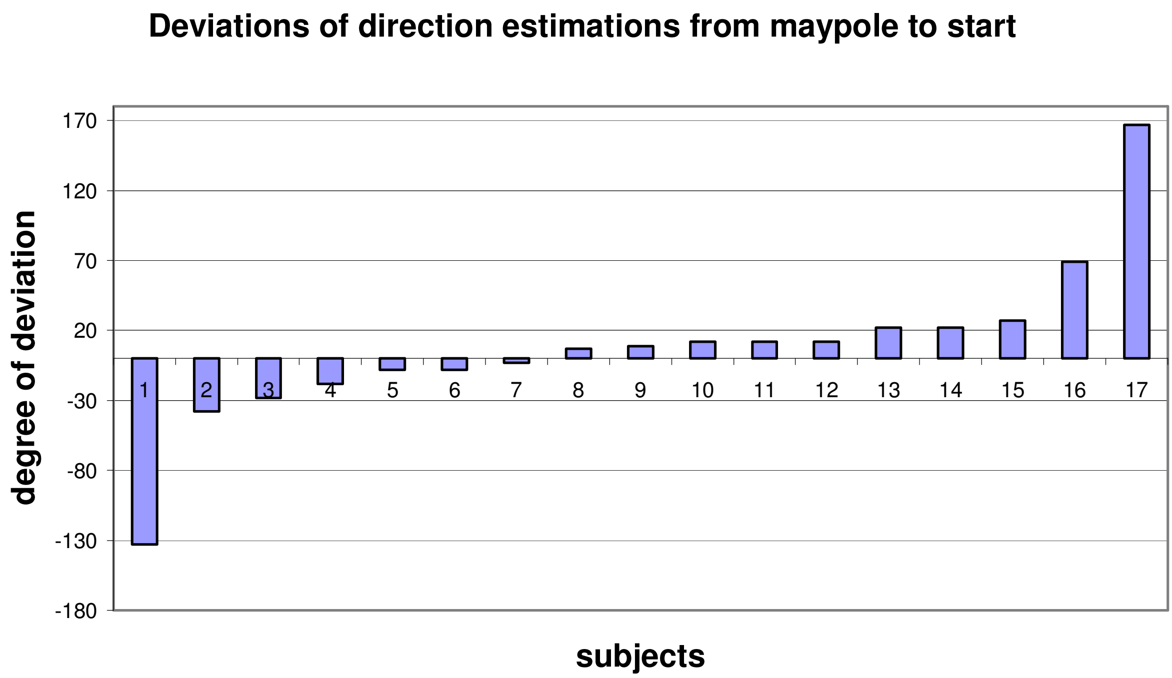

Figure 24: Deviations of direction estimations from maypole to start

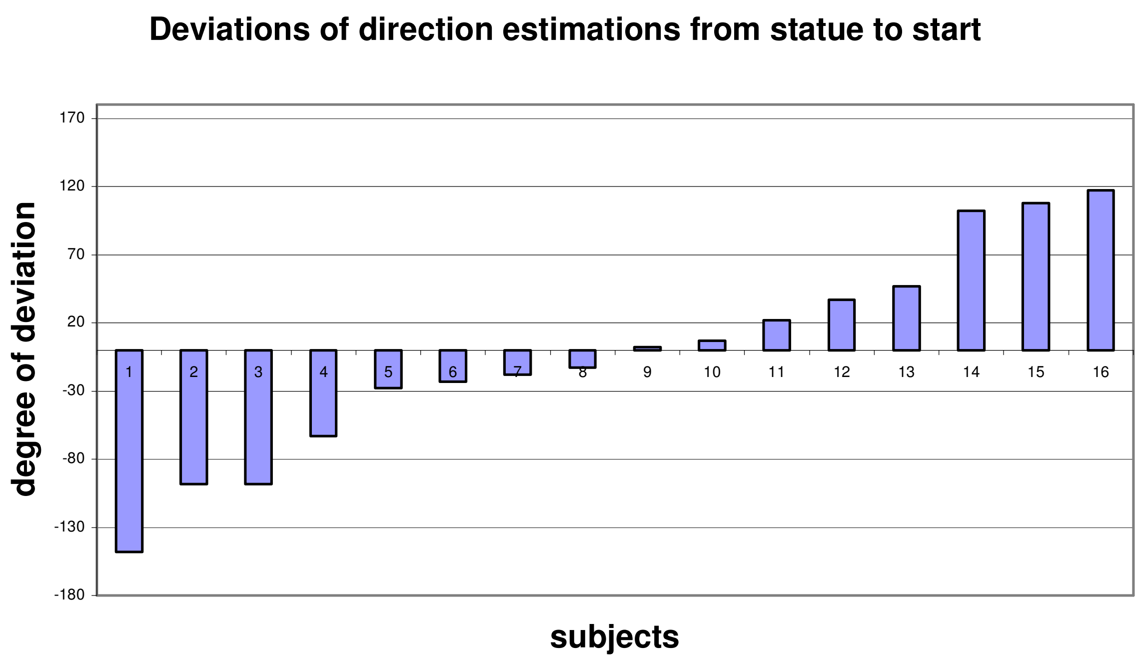

Figure 25: Deviations of direction estimations from statue to start

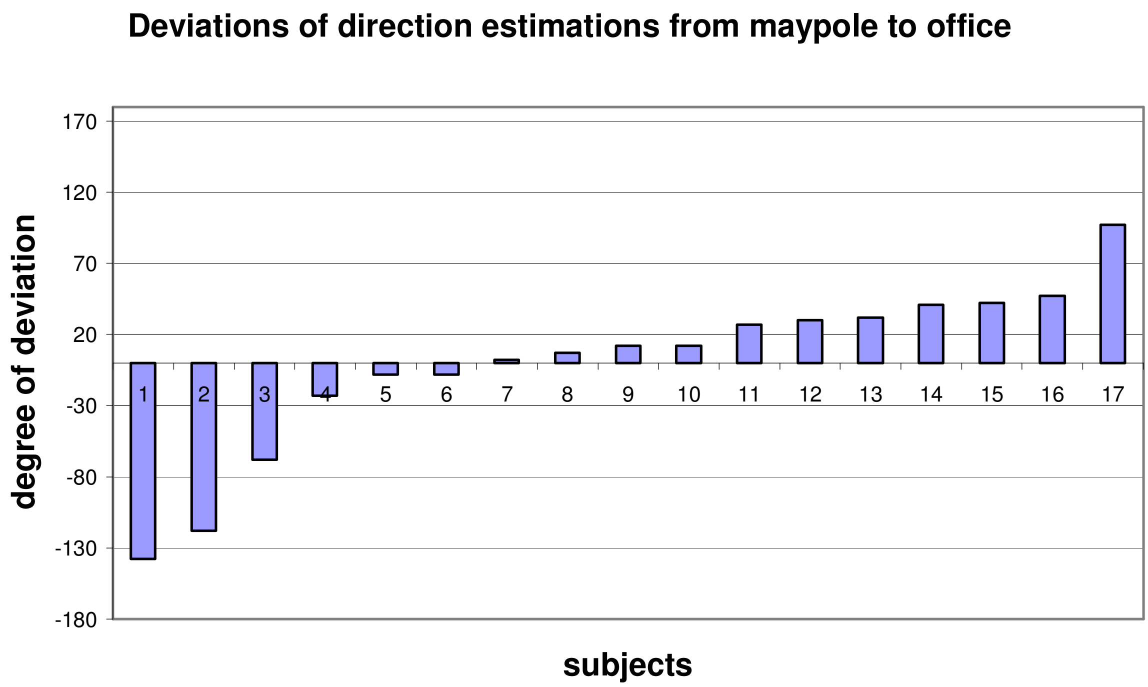

Figure 26: Deviations of direction estimations from maypole to office

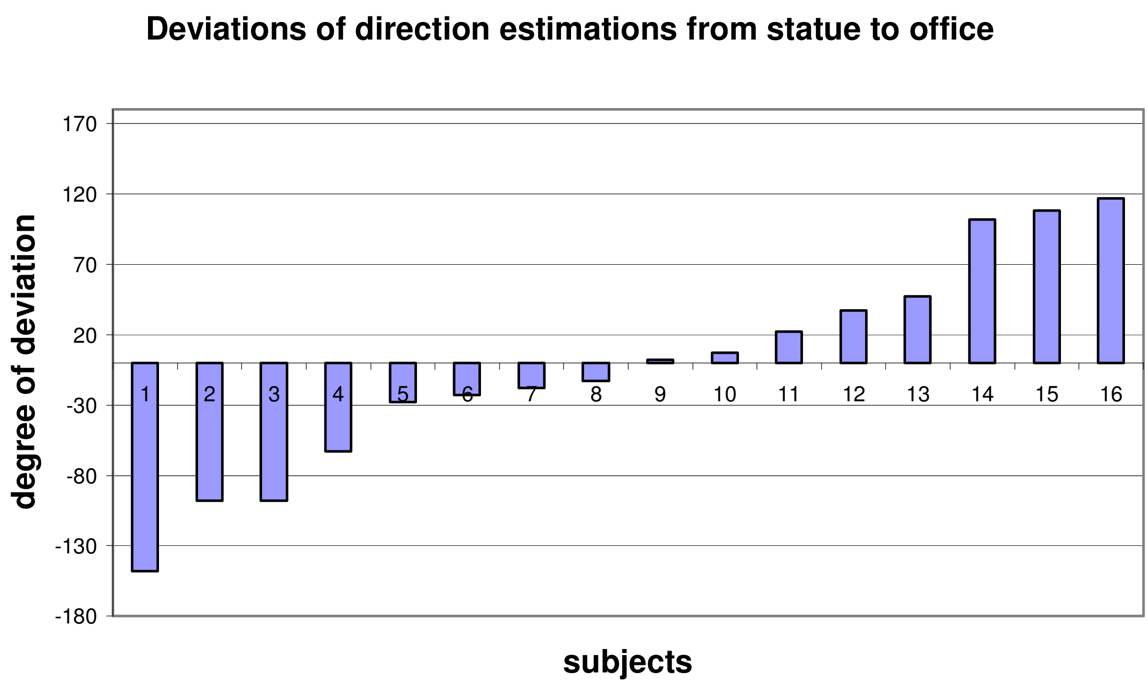

Figure 27: Deviations of direction estimations from statue to office

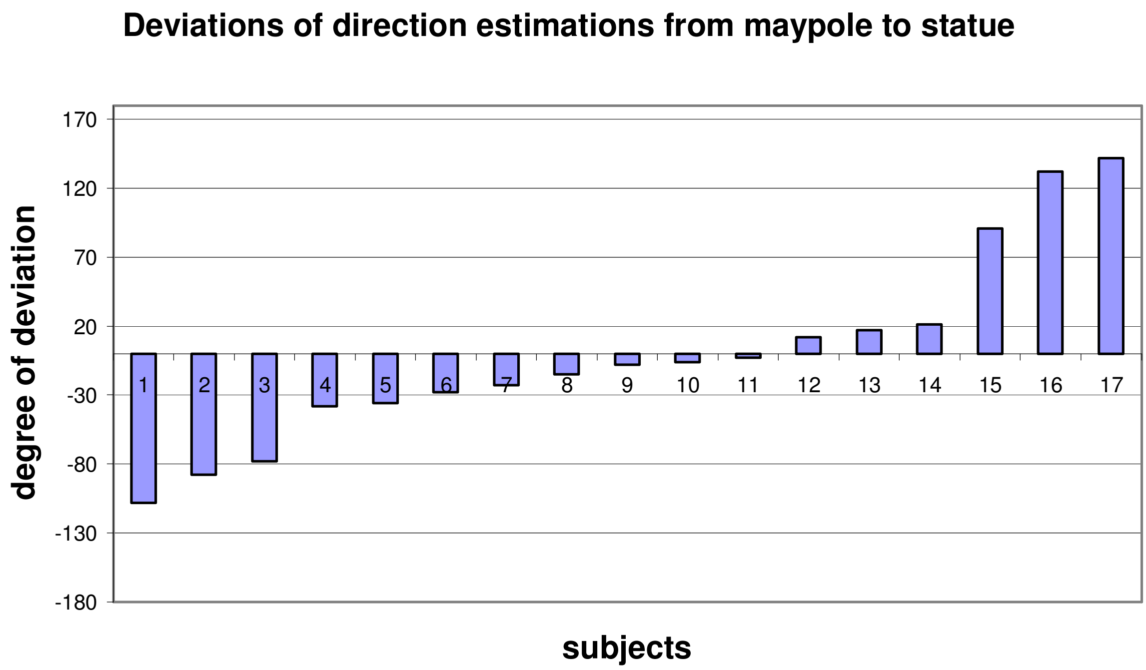

Figure 28: Deviations of direction estimations from maypole to statue

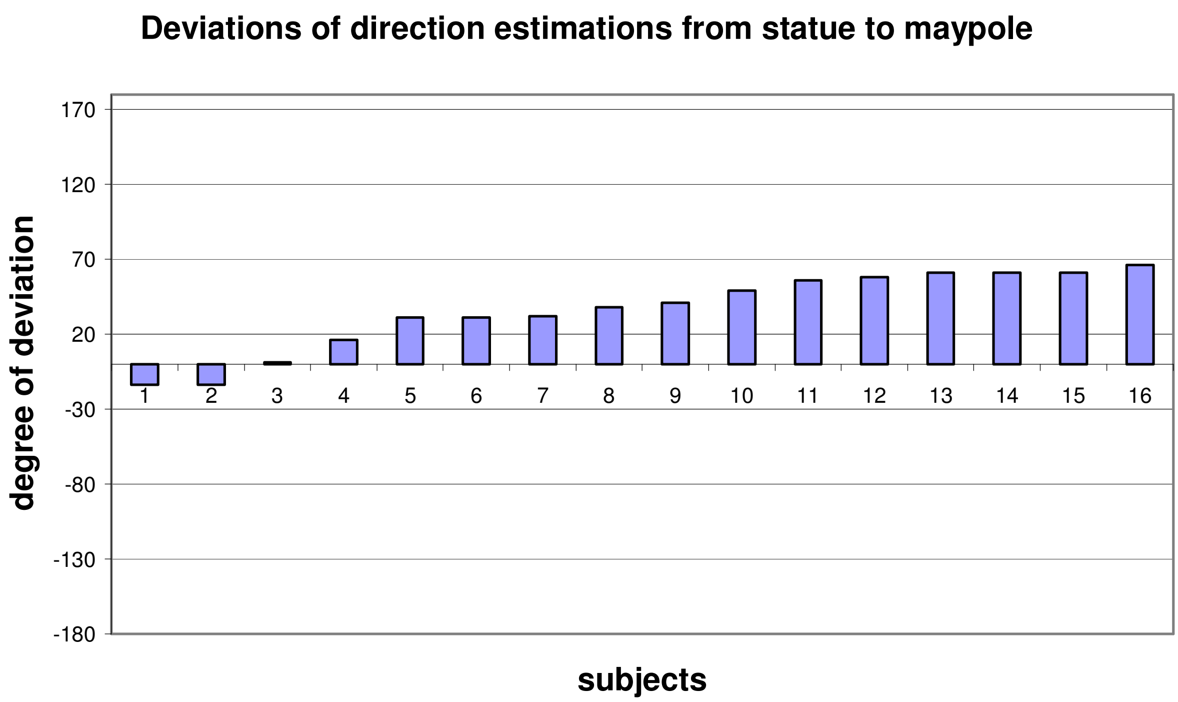

Figure 29: Deviations of direction estimations from statue to maypole

3.2.4.3 Subjects' evaluations of own direction estimations

After the three direction estimations, subjects were asked how certain they were about each of their estimations. The answer was indicated on a five point rating-scale. Subjects' evaluations of own direction estimations correlate with each other on a medium to high level , i.e. subjects being sure about one direction are likely to be sure about the other directions, as well. However, the actual deviations and the related self evaluations do not correlate. Only in the case of the office, both variables correlate on a low level. Table 24 shows the mean deviations of the different rating groups.

Evaluation of own direction estimation	Mean deviation Start	Mean deviation Office	Mean deviation Maypole or Statue
Very certain	16.8°	18.8°	60.3°
Certain	32.1°	43.5°	41.2°
medium	32.2°	38.1°	59.6°
Uncertain	30.7°	73.8°	48.5°
Totally uncertain	13.5°	29.5°	37.3°
Correlation between deviation and evaluation (r)	.039	.248	-.088

Table 24: Means of direction estimation deviations grouped according to the subject's evaluation of their own estimation, correlations between objective deviation and subjective evaluation

Both at the start and at the office estimation, the very certain and the totally uncertain group have the least deviations.

At the maypole/statue estimation, the very certain group has the worst estimations, whereas the totally uncertain group has the best estimations.

Interestingly enough, the totally uncertain group features two times the best (start and maypole/statue estimation) and in one case the second best direction estimations.

3.2.4.4 Direction estimations and navigation performance

Successful navigators in VR have significantly lower deviations from the correct direction than unsuccessful navigators (average deviations in case of navigation success: $\bar{x}$=36°, σ=23°, in case of navigation failure: $\bar{x}$=56°, σ=28, t-test: df=38, p=.033, r^2=11%). The difference effect is high (effect size: d=0.78). Despite the significant effect with regard to success, there are no significant correlations between the sum of deviations and the durations of the navigation with standardized route descriptions and with own route descriptions in VR.

3.2.4.5 Strategies used to estimate directions

After the last direction estimation, subjects were also asked which strategies they used to estimate the directions. Most subjects (87%) use one or two strategies. The number of strategies do not correlate with direction estimation deviations, i.e. subjects using more strategies, do not estimate directions more accurately.
Figure 30 indicates the percentage of subjects using the different strategies.

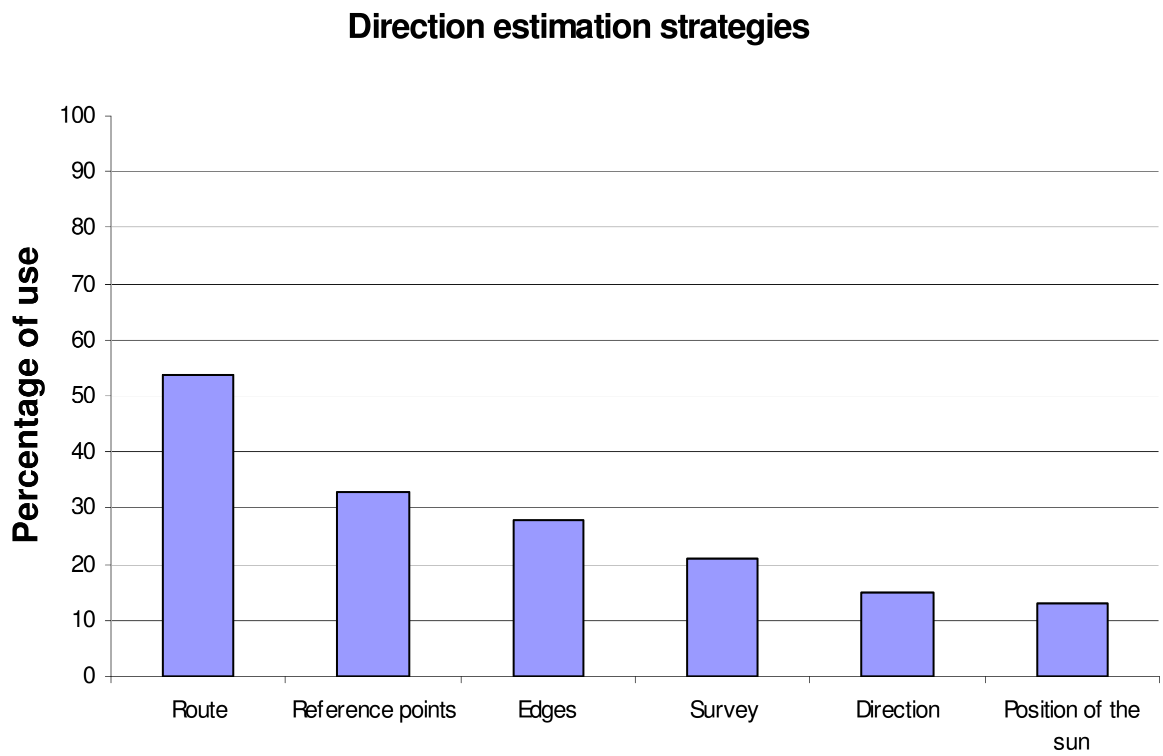

Figure 30: Strategies used for direction estimations, percentage of subjects who used a certain strategy

More than half of subjects (54%) trace the walked route back to the point in question. One third (33%) use landmarks as points of reference, 13% use the position of the sun for orientation, and 28% are oriented towards the experimental environment's edges, namely the streets and the fence surrounding the campus.
The other two strategies stated by subjects could be based on cognitive maps: 15% remember basic directions which may be based on a survey including the main paths, and again on the experimental environment's edges. 21% said they used the survey they had of the area, i.e. in addition to the main paths, their survey may contain e.g. large buildings.

3.2.5 Map task

3.2.5.1 Performance

At the end of the experiment, subjects received structural maps of the experimental area, indicating the form of paths/streets and buildings (see Figure 31).

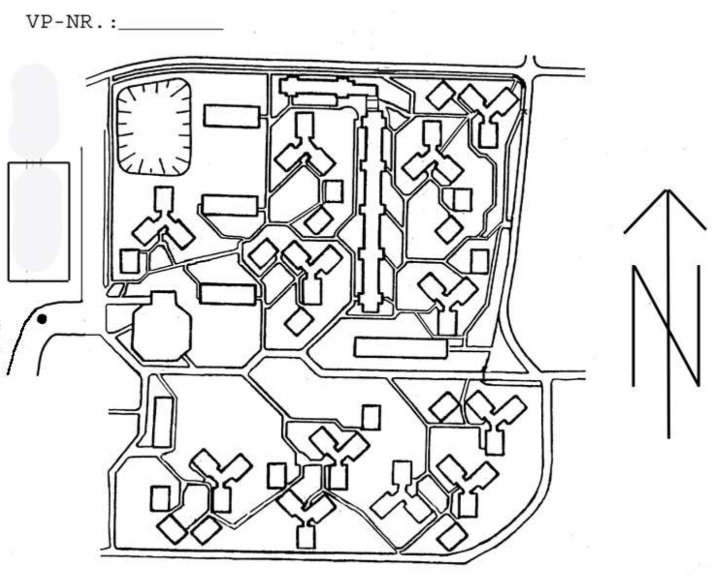

Figure 31: Structural map of the campus

The subjects' task was to mark the walked routes and remembered landmarks on the maps. The correctness of the marked routes and landmarks, the number of landmarks, and the time needed to do so constitute the subject's grade for this task (see Figure 32). Grades range from 1 (very good) to 5 (bad). Very good performance (grade 1) is defined by quick and absolutely correct marking of both routes and several landmarks. 18% quickly completed the task without any mistake.

Most subjects are able to indicate both routes and some landmarks with a few mistakes and receive grade 2 (44%) and some subjects who take more time or make more than 2 mistakes they receive grade 3 (31%). Only 8% (3 subjects) had large problems to orientate themselves on the given map and therefore receive grade 4 (2 subjects) and 5% (1 subject) could not recognize anything at all (grade 5).

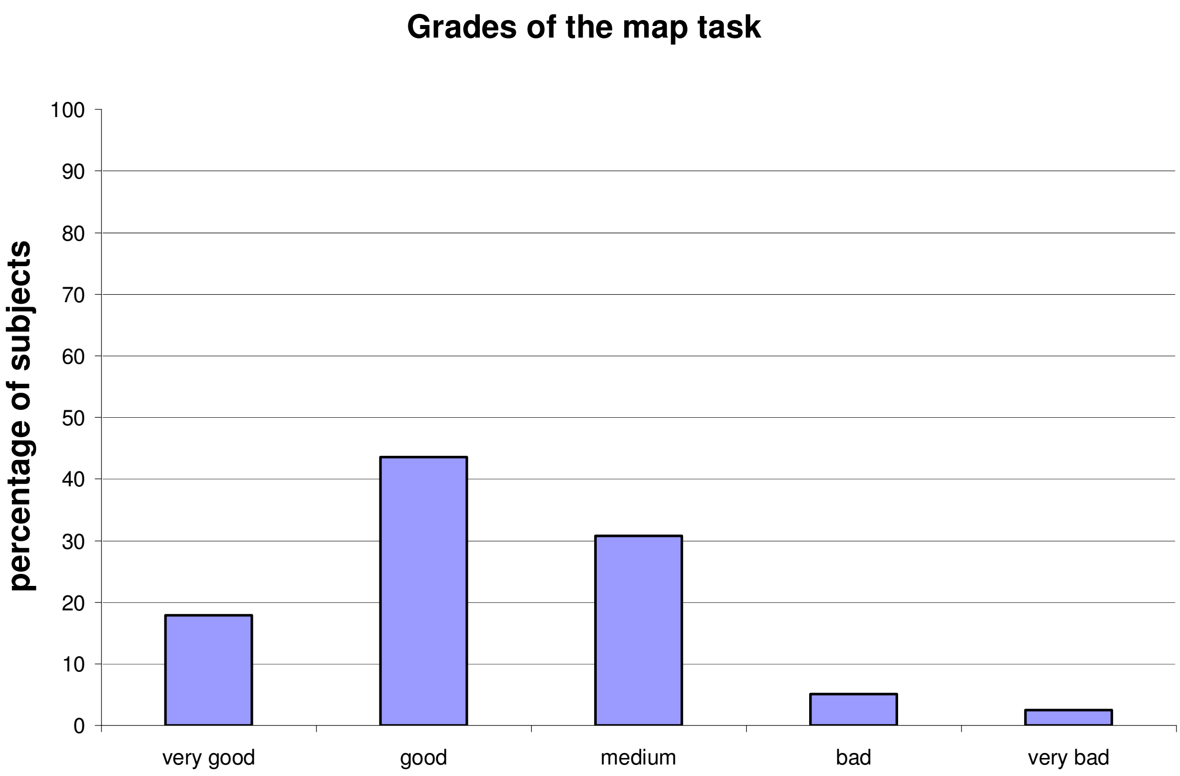

Figure 32: Grades subjects received for the accomplishment of the map task: beams indicate the percentage of subjects who have received a certain grade

3.2.5.2 Effects of availability of route descriptions

As I was wondering whether the availability of the own or the standardized route description would facilitate marking the routes on the map, subjects were handed two maps for each route. On the first map, subjects had to mark the route without route description, on the second map, subjects could use the familiar route description from the experiment to mark routes and landmarks. Results show that performance doesn't increase with the route description at hand (see Table 25).

The first walked route, which subjects got to know on the guided tour, described afterwards, and finally searched during navigation in VR will be called route 1 in this chapter (maypole route for design groups A and B, statue route for design groups C and D). Route 2 is the second walked route, on which subjects navigated with the standardized route description. On each map, the correctness of the indicated route was rated on a 3 point scale (1: totally correct route from start to goal, 2: correct route with a few mistakes, 3: no route or wrong route). Contrary to map task performance, the speed of task accomplishment is not considered here.

	Route 1		Route 2	
	First map	Second map	First map	Second map
Mean: points for correctness of routes	1.4	1.4	1.8	1.7
Subjects indicating the totally correct route (3 points)	69%	67%	46%	54%

Table 25: Route correctness on the four maps

3.2.5.3 Effects of type of route descriptions

Furthermore, I expected the groups navigating with the route description based on landmarks (A and C) to mark significantly more landmarks on the two maps in question (maps 3 and 4). Indeed, subjects who navigated with the landmarks route description and thereby focused on landmarks, are able to mark significantly more landmarks on those maps ($\bar{x}$=8.21, σ=4.55) than subjects who navigated with the help of route sequences ($\bar{x}$=5.45, σ=2.90; t-test: df=37, p=.032, r^2=9%, d=0.72).

3.2.5.4 Correlations between map task performance and other performance measures

The map task grades in the experiment correlate significantly with the frequency of map usage (r=.362, p=.023) and the frequency of orientation situations (r=.566, p<.001) in everyday life (see Table 26).

Besides, the more time a subject spends to produce the route description and at both navigation tasks, the longer he/she also takes at the map task.

Correlating variables	Correlation	P-value	shared variance	Tendency
Map task time and route description production time	.341	.033	12%	The longer someone takes at the map task, the longer he/she takes to write his/her route descriptions.
Map task time and navigation duration with standardized route description	.387	.015	15%	The longer someone takes at the map task, the longer he/she takes at navigation with standardized route description
Map task time and navigation duration in VR	.537	<.001	29%	The longer someone takes at the map task, the longer he/she takes at navigation in VR.

Table 26: Correlation of time needed at the map task with other variables

The map task grades in the experiment correlate significantly with the frequency of map usage ($r=.362$, $p=.023$) and the frequency of orientation situations ($r=.566$, $p<.001$) in everyday life (see Table 26).
Besides, the more time a subject spends to produce the route description and at both navigation tasks, the longer he/she also takes at the map task.

3.2.6 Self evaluation

<u>3.2.6.1 Items and frequencies</u>

Four items ask for the subject's evaluation of their navigation abilities. At the very beginning of the experiment, they are asked to rate themselves on a five-point rating scale (grades from 1, very good, to 5, very bad) and additionally to indicate how they are usually assessed by others. With the questionnaire to fill in at the end of the experiment, they are asked again to evaluate themselves and if their navigation performance during the experiment was better, worse or about the same than in everyday life.
In addition, subjects are asked to evaluate their performance at a specific task, the direction estimation. The concerning results were presented in Chapter 3.2.4.3.

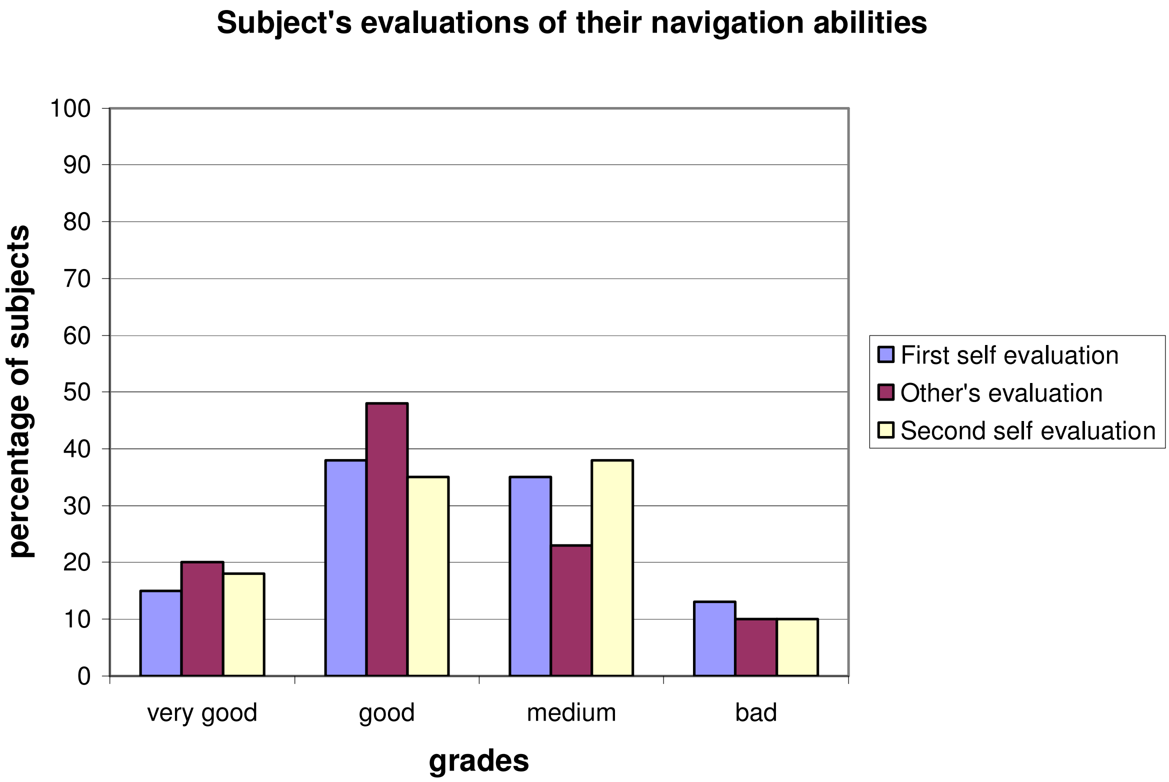

Figure 33: Subjects’ ratings of their navigation abilities on a five-point rating scale

Figure 33 describes the percentages of subjects who decided for the respective grades. None of the subjects consider his/her navigation abilities very bad, thus this grade is not depicted in Figure 33.

Correlating variables	Correlation	P-value	shared variance	Tendency
first and second self-evaluation	.734	<.001	54%	The higher the first self-evaluation, the higher the second self-evaluation.
other’s evaluation and second self-evaluation	.661	<.001	44%	The higher the other’s evaluation, the higher the second self-evaluation.
first self-evaluation and other’s evaluation	.674	<.001	45%	The higher the first self-evaluation, the higher the other’s evaluation.

Table 27: Correlations of self- and other’s evaluations

More than 70% of the subjects consider themselves to be good or medium navigators. Thus, less than 30% decide for extremer grades. 16% assess “very good”, whereas more than 11% assess “bad”. The evaluations intercorrelate on a medium to high level ranging from .66 to .74 (see Table 27).

The t-test does not show any significant differences between first self and second self and other’s evaluation. Most subjects evaluate themselves consistently.

Comparing navigation performance during the experiment with the related performance in everyday life, 80% of our subjects said that navigation performance at the experiment and in everyday life correspond. For this group, both self evaluations correlate significantly ($p<.001$) and on a high level ($r=.84$). The remaining 20% said that they performed worse during the experiment. For that group, both self evaluations correlate on a medium, but not statistically significant level ($r=.56$).

3.2.6.2 Relations to other variables

Self-evaluation and objective performance measures correlate on a low level. Correlations do not increase in case of the objective measures of navigation performance, but with regard to subjects’ subjective evaluation of direction estimation. Furthermore, self and others’ evaluations correlate significantly with the expert evaluation of route descriptions.

Table 28 provides correlations between self-evaluations and orientation and navigation performance.

Correlating variables	Correlation	P-value	Tendency
first self-evaluation and navigation duration in VR	.294	.066	The higher the first self-evaluation, the faster navigation in VR.
second self-evaluation and navigation duration in VR	.275	.086	The higher the second self-evaluation, the faster navigation in VR.
first self-evaluation and direction estimation performance	.314	.048	The higher the first self-evaluation, the better the direction estimation performance.
second self-evaluation and direction estimation performance	.184	.255	The higher the second self-evaluation, the better the direction estimation performance.
first self-evaluation and subject's direction estimation evaluation	.241	.134	The higher the first self-evaluation, the better the subject's direction estimation evaluation.
second self-evaluation and subject's direction estimation evaluation	.494	.001	The higher the second self-evaluation, the better the subject's direction estimation evaluation.
first self-evaluation and expert evaluation of the route description	.354	.027	The higher the first self-evaluation, the better the expert evaluation of the route description.
second self-evaluation and expert evaluation of the route description	.224	.170	The higher the second self-evaluation, the better the expert evaluation of the route description.
other's evaluation and expert evaluation of the route description	.322	.046	The higher the other's evaluation, the better the expert evaluation of the route description.

Table 28: Correlations between self-evaluations and orientation and navigation performance

3.2.6.3 Information sources used to navigate in unfamiliar environments.

In the questionnaire at the end of the experiment, subjects were asked which sources of information they use when navigating in an unknown environment and in which order they use them. Most subjects use various sources, beginning with reading a map (the first navigation aid used by 64% of subjects, see Table 29), followed by reading signboards. If those strategies are not successful, many subjects ask passers-by for route descriptions. The strategy “trying” is used by almost two thirds of subjects and according to subjects’ comments, they do so particularly if other sources of information are not available.

With respect to the map task at the end of the experiment, I asked subjects more specifically about the frequency of their map usage. Here, all subjects use maps, but two thirds use maps only monthly (35%) or a few times per year (33%). The remaining subjects use maps weekly (20%) or even daily (13%).

Sequence of using the navigation aid	maps	Verbal route descriptions	signboards	Just trying
First	**64**	14	28	8
Second	19	17	**36**	3
Third	6	**33**	8	17
Fourth	0	17	6	28
Fifth	0	6	0	6
Not used	11	14	22	**39**

Table 29: Percentage of subjects using the respective navigation aids in the presented sequence

3.2.7 Sociodemographic factors

3.2.7.1 Gender

3.2.7.1.1 Route description

Comparing the sexes, there are no significant differences with regard to route description classes used and descriptions’ quality. Though, I noted that women use significantly more crucial and less redundant sequences.

This corresponds to the fact that men take more time to produce the route descriptions (see Table 30). Moreover, women’s route descriptions receive tendencially better evaluations from both experts. Expert evaluation is done on a rating scale from 0 (useless) to 4 (very good).

However, these results are not statistically significant. Gender differences are neither confirmed by the second route description quality measure, information content, which indicates the ratio of described crucial sequences to the necessary number of crucial sequences.

	men		**women**		**t-test**			
	$\bar{x}$	σ	$\bar{x}$	σ	p-value	df	Effect size	r^2
Redundant/crucial sequences ratio	1.23	1.65	0.67	0.51	.041	38	.46	2%
Production time	7'58	3'14"	6'9"	2'7"	.179	37	.67	12%
Expert evaluation	2.1	1.06	2.4	1.08	.356	37	.28	3%
Information content	.59	0.22	.61	0.26	.792	37	.08	0%

Table 30: Gender differences with regard to route description measures

3.2.7.1.2 Direction estimation

Direction estimation evaluation grades range from 1 (totally sure) to 5 (totally unsure).

	men		**women**		**t-test**			
direction estimation evaluation	$\bar{x}$	σ	$\bar{x}$	σ	p-value (onesided)	df	effect size	r^2
start	2.26	0.99	2.62	0.92	.123	38	.38	2%
office	2.42	1.17	3.10	0.94	.028	38	.64	10%
other route's goal	2.74	1.24	3.48	1.12	.026	38	.63	10%
direction estimation deviations	$\bar{x}$	σ	$\bar{x}$	σ	p-value (twosided)	df	effect size	r^2
start	25°	20°	34°	42°	.367	38	.55	2%
office	39°	34°	53°	46°	.274	38	.35	6%
other route's goal	49°	36°	50°	40°	.888	38	.03	0%

Table 31: Gender differences with regard to subjective evaluations of direction estimation performance and actual performance

As with self-evaluation, men are more sure about their direction estimations than women. The difference between men's and women's evaluations is significant for the office and the other route's goal (maypole/statue) evaluation, but not for the start (see Table 31).

Objective performance data (direction estimation deviations) confirms the tendency that men estimate directions better than women (see Table 31). However, these gender differences are not significant.

3.2.7.1.3 Coherence between self evaluation and performance measures

The last chapter showed gender differences at subjective evaluation and at objective performance of direction estimations. Another question is if there are gender differences with regard to the coherence between self evaluation and performance measures, i.e. to what extent can men and women evaluate their performance realistically. The following Tables 32 and 33 show only the significant correlations between self evaluation and performance variables, separately for men and women.

Correlating variables (female subgroup)	Correlation	P-value	shared variance	Tendency
first self-evaluation and information content of subject's route description	.516	.017	27%	The higher the first self-evaluation, the higher the information content of the subject's route description.
second self-evaluation and information content of subject's route description	.434	.049	19%	The higher the second self-evaluation, the higher the information content of the subject's route description.
first self-evaluation and expert evaluation of subject's route description	.466	.039	22%	The higher the first self-evaluation, the higher the expert evaluation of the subject's route description.

Table 32: Correlations between self evaluation and performance measures at the female subgroup

Women's general evaluation of navigation abilities correlates significantly with route description quality measures. However, there is neither coherence with navigation performance and nor between direction estimation evaluation and performance.

Men's general evaluation of navigation abilities correlates significantly with the frequency of orientation situations, the average deviation of direction estimations and the average self evaluated certainty of direction estimations. With regard to the coherence between direction estimation evaluation and performance, there is one significant relation (direction estimation to the office).

Correlating variables (male subgroup)	Correlation	P-value	shared variance	Tendency
first self-evaluation and frequency of orientation situations	.528	.020	28%	The higher the first self-evaluation, the higher the frequency of orientation situations.
second self-evaluation and frequency of orientation situations	.608	.006	37%	The higher the second self-evaluation, the higher the frequency of orientation situations.
first self-evaluation and average deviation of direction estimations	.608	.006	37%	The higher the first self-evaluation, the better the subject's average direction estimation performance.
second self-evaluation and average deviation of direction estimations	.526	.021	28%	The higher the second self-evaluation, the better the subject's average direction estimation performance.
second self-evaluation and average self evaluated certainty of direction estimations	.660	.002	44%	The higher the second self-evaluation, the higher the subject's average certainty of direction estimations.
Certainty and real deviation of direction estimation to the office	.490	.033	24%	The more certain a subject is about his/her direction estimation (self evaluation) to the office, the better the direction estimation.

Table 33: Correlations between self evaluation and performance measures at the male subgroup

3.2.7.1.4 Self evaluation

On average, men ascribe themselves better evaluations than women. T-tests reveal significant gender differences for the second self evaluation and for other's evaluation (see Table 34). With regard to the first self evaluation, the tendency that men are evaluated to be better navigators is the same, but does not prove statistically significant. The hypothesis that men award themselves better navigation grades can be confirmed for two out of three evaluations. However, women's evaluations do not increase as expected, i.e. after the experiment. Table 34 shows the respective means, standard deviations, and t-test results. Evaluations are indicated on a five-point rating scale ranging from 1 (very good) to 5 (very bad).

	men		**women**		**t-test**			
	$\bar{x}$	σ	$\bar{x}$	σ	p-value onesided	df	effect size	r^2
First self evaluation	2.21	0.92	2.67	0.86	.056	38	.52	7%
second self evaluation	2.05	0.848	2.71	0.845	.009	38	.78	15%
other's evaluation	1.95	0.780	2.48	0.928	.030	38	.62	10%

Table 34: Gender differences with regard to subjective evaluations of navigation abilities

3.2.7.2 Means of transportation

I asked subjects to indicate their mostly used means of transportation. Some subjects who use regularly two means of transportation indicated both. Possible answers were

- by foot (28%),
- by bike (25%),
- by motorbike (10%),
- by car (48%), and
- by public transportation system (60%).

The means of transportation is not related to navigation performance, but to direction estimation performance. Subjects usually using their car perform better than the non-car users (average deviation for car users: $\bar{x}$=34°, for non-car users: $\bar{x}$=48°, t-test: p=.085, df=38), whereas subjects usually using the local public transportation system perform tendencially worse at estimating directions.

Another result shows that subjects often going on foot produce their route descriptions significantly faster ($\bar{x}$=5'34'', σ=2'1'';t-test: p=.044, df=38, r^2=12%, d=0.80) than non-pedestrians ($\bar{x}$=7'34'', σ=2'55''), which may be an effect of the task, because these route descriptions aim at pedestrians. In addition, pedestrians receive significantly better grades for the map task ($\bar{x}_{pedestrians}$=1.8, $\sigma_{pedestrians}$=0.79, $\bar{x}_{non\text{-}pedestrians}$=2.5, $\sigma_{non\text{-}pedestrians}$=0.90, t-test: p=.042, df=37, r^2=11%, d=.83).

3.2.7.3 Contiguity between sociodemographic and performance variables

The sociodemographic variables age, gender, and frequency of orientation situations are (significantly) related to various performance measures (see Table 35).
As expected the amount of subjects' previous orientation experiences, expressed by the frequency of orientation situations, correlates significantly with various measures of performance. Thereby, it is remarkable that it is related to all performance indicators of the map task.

Correlating variables	*Correlation*	*P-value*	*Tendency*
Age and number of route description classes	.303	.057	The older the subject, the higher the number of classes used.
Age and navigation duration in VR	.352	.026	The older the subject, the longer the navigation in VR.
Age and map task grade	.335	.037	The younger the subject, the better the grade for the map task.
Gender and biking	-.35	.029	Women use the bicycle more often as a means of transportation.
Gender and landmarks marked on map	.373	.019	Men mark significantly more landmarks on the map.
Frequency of orientation situations and route description production time	.329	.038	The more often a subject experiences orientation situations, the faster he writes his directions.
Frequency of orientation situations and navigation duration with standardized route descriptions	.313	.049	The more often a subject experiences orientation situations, the faster he navigates with the standardized route description.
Frequency of orientation situations and navigation duration in VR	.324	.042	The more often a subject experiences orientation situations, the faster he navigates in VR.
Frequency of orientation situations and Map task grade	.566	.000	The more often a subject experiences orientation situations, the better he/she marks routes and landmarks on the maps.
Frequency of orientation situations and sum of marked landmarks on the maps	-.361	.024	The more often a subject experiences orientation situations, the more landmarks he/she marks on the map.
Frequency of orientation situations and time needed for the map task	.386	.015	The more often a subject experiences orientation situations, the faster he/she accomplishes the map task.
Number of moves and navigation duration with stand. route description	-.483	.002	The more often a subject has moved to another town, the faster he navigates with the standardized route descriptions.

Table 35: Correlations between sociodemographic and performance variables

3.3 Discussion

The design of the experiment (depicted in Table 36) was created in order to investigate the effects of two standardized route descriptions on navigation performance and the effects of route familiarity on composition and quality of ordinary route descriptions.

Furthermore, I researched if subjects are able to give good direction estimations in a hardly known area and if self-evaluations of orientation and navigation abilities correspond to objective measures of performance.

Task \ Group	**A**	**B**	**C**	**D**
R: goal of first walk	maypole	maypole	statue	statue
navigation aid	guided tour	guided tour	guided tour	guided tour
R: goal of second walk	statue	statue	maypole	maypole
navigation aid	standard route description based on landmarks	standard route description based on route sequences	standard route description based on landmarks	standard route description based on route sequences
VR: goal of third walk	maypole	maypole	statue	statue
navigation aid	memory and own route description	memory and own route description	memory and own route description	memory and own route description

Table 36: Experimental design

Effect sizes of significant differences in this experiment range from middle to high level indicating a reasonable, significant effect of the independent variables. However, a single independent variable explains only 5 to 15% of the variance of the performance measures, which does not devalue its importance, but indicates that there is a larger number of factors influencing complex human behavior, like spatial behavior.

3.3.1 Route description

3.3.1.1 Route description quality

The first experiment shows that there are many different ways (i.e. navigation strategies) to reach a goal successfully and likewise, there are also many different ways to describe the route to a goal successfully. Successful means that the statement describes the sequence in a way so that the hearer can take the correct continuation of the route, but not the existence of certain kinds of route description components or specific wording.

In the experiment, route description quality is determined by expert evaluation and by information content, which indicates if all absolutely necessary (i.e. crucial) sequences are included and described comprehensibly. The criterion Information Content (IC) is constituted by the ratio of described crucial sequences to the necessary number of crucial sequences. The remaining sequences (100%-IC) are not described at all, they are not described comprehensibly, or they are redundant. Statements that are made to describe a sequence in addition to the already existing crucial statement, are called redundant sequences.

Many subjects describe about the same number of crucial and redundant sequences and there are often pairs of crucial and redundant sequences describing what to do at a specific decision point.

Only a few subjects manage to describe all crucial sequences. On average, less than two thirds of the crucial sequences are described sufficiently, i.e. most of the subjects' route descriptions do not cover all decisive points and therefore potential users are likely to unwittingly leave the route before reaching the goal. This confirms Kalbow's (1993) results that ordinary route descriptions (i.e. spontaneous descriptions given by lay-persons) do not constitute a good navigation aid. In everyday life, people who rely on route descriptions often have to ask passers-by at several sequences of the route.

Nevertheless, the average number of described sequences corresponds to Miller (1956) who found that ordinary people are able to keep 7+-2 chunks in mind. Thus, route descriptions were probably better if the chosen route had less decision points and sequences or if the sequences could be summarized to up to seven chunks.

One question was if there are notable correlations between the quality measures of route descriptions and the time needed to produce the route descriptions. However, I found that taking more time to produce route descriptions increases the total number of statements and classes, but it does not necessarily increase the number of crucial sequences and thereby the route description quality. Actually, it is foremost the number of redundant sequences which increases with production time.

A certain number of **redundant statements** may function as confirmation and therefore add information facilitating the navigation decision, whereas a large number of redundant statements may provoke an information overload of the hearer. Especially if the route description is provided only once and vocally, if the described route is rather complex, contains a large number of decision points and therefore features a high number of crucial sequences, the hearer's memory may be overcharged if he has to remember additional cues. The number of chunks to remember should not exceed seven (Miller, 1956).

Contrary to that, if the user disposes of a written description or if a user who is driving the car has a helpful co-driver who can take over reading the description, one or two additional cues per crucial sequence may be helpful. It also makes a difference if the user disposes of previous knowledge of the area and if he/she will have the possibility to ask again.

When evaluating the subjects' route descriptions, the criterion is the question if a user who does not know the area would find the route to the goal with the route description without any other navigation aids.

Assuming that crucial sequences are necessary and sufficient for a good route description, why do subjects add so-called redundant statements to their route descriptions? Supposedly, redundant sequences are used to further describe and confirm action guidelines. Usually route descriptions are made for other people's use. Therefore, subjects may want to offer more pieces of information in order to make sure that there are enough pieces of information that can be used. Their aim may be rather certainty that the user understands the description than brevity of the route description. We do not know if subjects are conscious of describing the same decision point twice and if they consider the additional information to be essential or if they consider the crucial and the redundant pieces of information to form one chunk. Subjects may define crucial and redundant sequences differently.

Thus, I conclude that the effects of redundant sequences cannot generally be considered good or bad, but depend on various factors, to name

- the route (length, availability of landmarks, complexity, number of decision points),
- the type of route description (verbal vs. written, total number of sequences),
- the availability of additional help (signboards, possibility to ask again, map, accompanying person) and
- both communicators' abilities and expectations (agreement on definitions, common knowledge of terms, coincidence of means of transportation, memory performance, field dependence, previous knowledge about the environment).

3.3.1.2 Textual analysis of route descriptions

To categorize the route descriptions' components, I went back to Denis' (1997) schema focusing on landmarks, in my opinion an important, but not the only component of route descriptions. Therefore, I completed his classification with classes based on the navigation strategies used at my first experiment.

Depending on the number of sequences concerned, I distinguish local cues (information about one sequence, namely distances referring to consecutive sequences, route sequences, classes referring to landmarks) and global cues (information about the route/area that can be used at various sequences, namely direction and exclusion principle referring to districts). The local cues dominate which is surely due to the fact that start and goal are within one district and that indications of beeline directions are difficult to describe verbally. Route descriptions are mainly composed of local cues containing landmark and route information. This proves that many people do develop landmark and route knowledge of a recently trained route in a quite unfamiliar area.

Subjects' route descriptions show that there are many different classes of route description components. These classes are combined differently by subjects and various combinations are considered to fulfill criteria for a good description. While the first experiment shows that there are many different ways (i.e. navigation strategies) to reach a goal successfully, likewise the second experiment shows that there are also many different ways to describe the route to a goal successfully.

Action guideline with landmark reference is the favored class covering one third of all sequences (average of all route descriptions) and, in addition, correlates positively (and significantly) with the quality measure expert evaluation. These results are not surprising, as this class includes both central aspects of route descriptions, namely (mental) positioning and action guideline. So, the hearer learns where to do what. In addition, he knows whether he is on the right track, as the next landmark can function as confirmation, as well. Other frequently used landmark related classes are landmark description and path character.

Landmarks are important for navigation and therefore a popular research object. The multiple functions of landmarks, e.g. association with route decisions, confirmation to be on the correct route, allocentric frame of reference, and their sufficient availability are surely reasons for their popularity. My results confirm both the landmarks' popularity of use and their account for route description quality.

Another very frequent class is **route sequences**, which shows both that they are a frequently used component of route descriptions and that route knowledge can be developed at first contact with an environment.

Landmarks and route sequences are most often used classes of route descriptions. However, its successful usage requires the agreements of speaker and hearer about the definitions of the used objects. For example, the hearer needs to know what is considered a street if he/she has to make a turn at the third street. The hearer may pass a small lane reserved for pedestrians and bikers and probably does not know if the speaker counted this lane or not. Implicit cultural knowledge is very important for the recognition of landmarks, e.g. if I was told to turn left at the church, I need to know what a church looks like in this area.

But even within one area or culture, a variety of names exist for the very same object (first experiment). Often these descriptions characterize very different things and

thereby evoke totally different imaginations of the real object which may not enable the hearer to recognize the described landmark.
For those reasons and in order to check if a well prepared definition of junction enables different people to find a route, experimental subjects received a good definition of junction in addition to the route description based on route sequences. The 100% success rate of the navigation task with the prepared route descriptions (all subjects reached the goal within the scheduled time) shows that it is possible to enable successful navigations by providing well prepared and defined route descriptions.

There are combinations of route description classes that are frequently used together (landmark related classes: Introduction and description of landmarks, action guideline with landmark reference, path character, street names and building numbers; for further description see Chapter 3.10.1), whereas there are other classes that rather exclude each other (direction and landmark classes). Subjects indicating the direction describe less landmarks, whereas subjects using one landmark class are likely to use other landmark classes, as well.
The route descriptions investigated are representative for written descriptions of urban environments. They are not typical for rural areas where popular features like buildings and paths are rarer.

3.3.1.3 The effects of route familiarity on route descriptions

Within the scope of the experiment, I further investigated the effects of route familiarity on route descriptions. Indeed, familiarity has a highly significant effect on the use of the two most frequently used classes, landmark related and sequenced route information. To describe unfamiliar routes, subjects use more landmark related information. Apparently, landmarks and its associated actions (e.g. to turn left at the gate) are well perceived at first field-walking. If the same subjects are asked to describe a route which is familiar to them and which is located in their accustomed environment (here, the way from their house to the next bakery/ supermarket), subjects rather describe route sequences, often additionally naming the streets where the hearer has to make his turn. As the same subjects provided route descriptions with varying familiarity, inter-individual differences cannot account for this result. The familiarity of the route (and necessarily the route) are the only varying variables.

3.3.2 Comparisons

3.3.2.3 Comparison of the components of route descriptions and navigation strategies

The following comparison regards navigation and route description strategies.

In the first experiment, the navigation strategies used by subjects were categorized into nine different classes of strategies. In the second experiment, route descriptions were analyzed with regard to navigation strategies they provide to the user, the so-called classes of route description components. Comparing the number of different strategy classes used for navigation and in route descriptions, it is found that route descriptions contain a significantly larger variety of classes than navigation strategies. Given that route descriptions should provide navigation strategies to the user who may not be able to take over all strategies provided in the route description, it does make sense to use a variety of classes when describing a route. The first experiment showed that subjects have inter-individually different personal preferences for specific strategies. However, if the route description provides only strategies which the user cannot use easily (e.g. only directions for a user who prefers to use landmarks for navigation), this route description may not enable the user to reach the goal.

The speaker (giving a route description) or a navigator knowing the route can choose the subjectively best way to describe each sequence or to navigate, whereas the user of a route description can choose only from the strategies available in the route description.

However, using several statements to describe one route sequence overcharges the hearer’s memory, if the total number of chunks exceeds the magical number 7+-2 (Miller, 1956) that people are usually able to remember. Thus, if there are only two route sequences to be described, the speaker can provide two or three strategies to cover one sequence. If however, the route consists of five sequences, the speaker should provide one chunk per sequence (or even try to form one chunk when describing two sequences, e.g. turn left twice) and provide additional pieces of information only at one or two sequences where it is really necessary to ensure the user's navigation success.

This raises the question if the variety or the contiguity of strategy classes is superior in good route descriptions.
On the one hand, strategic continuity enables the hearer to remember a sequence of guidelines as a chunk, e.g. a sequence of landmarks or turnings. However, similar cues may interfere with one another (e.g. did he say to turn left at the green house or at the red house?) and in case of non-landmark components, there is no confirmation that one is still on the correct route. Thus, even when describing route sequences continuously, the speaker should include a landmark for confirmation after a few sequences. Furthermore, many routes include some sequences that are better described by landmarks, e.g. in case of various departing paths that are difficult to count, whereas other sequences of the same route are better described by other components, e.g. if there are no good landmarks available at this decision point. So, not all sequences of a route may be best described by the same class of cues.
Probably, a good route description constitutes a compromise between continuity and variety that is adequate for the specific route and the user's abilities. If the speaker knows about the hearer's navigation abilities and preferences, he could provide more preferred classes. Anyway, especially in case of verbal route descriptions and thereby limited short-term memory capacity of the user, it is important that the hearer can form the route information to chunks whose number should be limited to 7+-2 (Miller, 1956).

In the discussion of the first experiment, I raised the question if the strategies used to navigate on a certain route (here the maypole route) actually correspond to the strategies provided to others, i.e. to the users of one's route description.
I found that several strategies occur in both experiments, especially landmarks that are the most often used strategy both for navigation and in route descriptions. In addition, the popularity of landmarks can be confirmed by the navigators of the second experiment, as well.
However, some strategies are apparently useful for own navigation, but difficult to explain. For example, exclusion principle is easy to use when navigating oneself (you

just don't go to unknown, but salient landmarks or avoid certain districts), but difficult to remember if it was part of a long description (he said something about this landmark, probably he meant that I should go there?). Another example is direction that appears as route description component especially because sketch maps were included into this category. Taking off the sketch maps that can only be used for written descriptions, there are only six uses of direction at route descriptions. The reason for this is supposedly the same than for exclusion principle, it's useful for own navigation, but hard to describe. Even if common terms like the points of the compass are used, this strategy requires the (speaker's and) hearer's knowledge of those in the current situation. The comparison of strategies implied by one's route description and navigation strategies within subjects (of the second experiment), shows similar use of direction in both situations. This result either contradicts the above finding that direction is rather used for own navigation and emphasizes the impact of inter-individual differences between the two experiments' samples or it shows that the own route description is frequently used during this navigation.
Other strategies are used particularly for route descriptions, probably, because they are supposed to be part of a metrically exact description. Distance, e.g., was used for route descriptions only (second experiment), but not as navigation strategy in the first experiment. This can be confirmed by the comparison of strategies within subjects, as well. Thus, the different usage of distance in route descriptions and for navigation is not the result of the differing sample (as in the previous chapter), as analyses with constant sample (like in this chapter analyses within subjects of the second experiment) show the same effects.

Taking into account the results of distance estimations received in the first experiment (description of this part of the experiment in Popp, Platzer, Eichner & Schade, 2004), this strategy features two contortions: the speaker might not make an exact distance estimation and the hearer, in addition, may further distort the distance. Our first experiment showed that most subjects were unable to give a good distance estimation, to some extent, of a distance measuring 571 meters. Estimations ranged from 200 to 800 meters which are no extreme values, but rather the ends of a one peak continuum. However, if distance information does make sense depends on a variety of factors, e.g. is it the only or additional information and the area in question;

It is useful if there are many departing paths or if the correct path is difficult to recognize (so the navigator knows where to look for the path), if it is enough to make a rough distance estimation (e.g. continue 5m, 50m or 500m), and if there are no good landmarks that could be used instead;

3.3.2.2 The effects of navigation information provided by route descriptions

Compared to navigation performance in the first experiment that was based on the subject's own experience, navigation performance based on standardized route descriptions is really good. All subjects navigating with our standardized descriptions find the goal within 20 minutes.

Different kinds of route descriptions may have different effects on the user's navigation. We created two kinds of route descriptions, each of them composed of mostly one class, landmarks or route sequences.

The landmark based description enables subjects to significantly faster navigation at the maypole-route. However, the kind of route descriptions does not have a significant effect on navigation duration at the statue route. There are a few reasons for the superiority of landmarks as description strategy for this route. The high number of complex junctions and departing paths complicates its description on the basis of route sequences. In contrast to that, most landmarks on this route can be perceived easily and are less equivocal. As landmarks may fulfill several functions (association with route decisions, confirmation, frame of reference), landmarks additionally confirm that the subject is on the right track. These results agree with other empirical studies, e.g. Jansen-Osmann (1998) who confirms the importance of landmarks as wayfinding aids.

3.3.4 Navigation in VR

3.3.3.1 Navigation performance in VR

The last navigation task is to find the first walk's route and goal in VR. Navigation aids are the subject's self-produced route description and what they remember of the route they took about an hour before.

Navigation performance in VR (duration) correlates significantly with RC, the ratio of redundant sequences to the number of crucial sequences. The less redundant sequences (relative to crucial sequences) are used, the faster the goal is retrieved in

VR. This coherence may mean that using a route description featuring many redundant sequences as navigation aid decreases navigation speed or just that subjects who describe more redundant sequences (and take longer to produce the route description) also take longer on navigation, i.e. their working speed to solve spatial tasks may be generally lower. This is further confirmed by the finding that the more time a subject spends to produce the route description and at both navigation tasks, the longer he/she also takes at the map task. Navigation performance in VR does not correlate significantly with any other measure of route description quality.

As described above, navigation aids of the navigation task in VR are the subject's self-produced route description and what they remember of the route they took about an hour before. Therefore, navigation performance results from route description quality and mental representation quality (knowledge available, but not transferred to the route description).

Navigation performance is related to RC, but there is no notable correlation between the more important route description quality measures, IC (information content) and expert rating, and navigation performance. Therefore, I assume that the other navigation aid, mental representation, plays a decisive role at this navigation process, even if a route description is used.

Probably this results from the small time gap of one hour between route training and navigation task which enables subjects to remember spatial information saved in their short-term memory. In addition, after walking on the route (time of encoding the spatial information), subjects have to remember this route information and transfer it to a route description. This transfer and elaboration fosters the encoding process and facilitates later remembrance. If there was no additional processing or if the time gap was longer (e.g. one week like at the first experiment), subjects would probably remember less spatial information and have to rely more on the route description.

Inversely, the important role of mental representation of the route also shows that a good mental representation may be a necessary, but not a sufficient supposition for a good route description. There are subjects who covered only half of the crucial sequences in their route description, but who showed good navigation performance on the route. It is possible that they were not willing or able to transfer large parts of their spatial knowledge to the route description. Another explanation may be that they often used the recognition strategy for navigation, i.e. they did not remember e.g. a landmark when writing the route description, but they recognize the landmark when seeing it on the route and can associate the correct action with it (e.g. to turn left at this landmark).

For this reason and because of the importance to adapt a route description to the hearer's knowledge and abilities, good navigators are not necessarily good route descriptors.

3.3.3.2 Navigation in VR with and without route description

The present data enables me to compare navigation performance on the same route (maypole-route) with varying conditions.

At the last navigation task of the second experiment, most subjects retrieved the route in the virtual campus with the aid of their memory and their own route description.

Comparing navigation performance depending on navigation aid, it results that a standardized route description enables subjects to similar performance as the combination of the two navigation aids subject's memory of the earlier walked route and own route description.

Comparing navigation performance at the maypole-route in the first and second experiment, it results that in the second experiment, subjects navigate faster and reach the goal more often than subjects in the first experiment (condition: training in R, then test in VR).

Conditions in both experiments are not exactly the same. In the first experiment, subjects did not know that the experiment deals with spatial knowledge acquisition and navigation. In addition, there was a one week break between training and test session which further increases task difficulty. After this first experiment, I was wondering if navigation performance would improve if subjects had known about the experiment's aim and the following navigation tasks from the very beginning of the experiment. The second experiment is not aimed at investigating particularly this question, but its results can give a hint towards the answer. Subjects taking part in the second experiment early learnt that the experiment deals with route descriptions and navigation. Like subjects of the first experiment, they are guided along the maypole-route. However, before they start walking, subjects are already told about their next task, to produce a route description of this route. During the test navigation of this route in VR, which follows approximately 45 minutes after the training, subjects are allowed to use their own route description. So, there are many factors facilitating navigation at the second experiment.

Nevertheless, taking into account all aids for the second experiment's navigation task, I would have expected an even higher success rate for this group. However, subjects' performances feature large inter-individual differences and the transfer of spatial knowledge from R to VR complicates the task in the second experiment, as well. With regard to the navigation task in VR, 40% of our subjects consider the transfer to VR to be easy or very easy, 30% consider the transfer difficulty to be medium, and the remaining 30% experience the transfer to be difficult. Of course, there may be subjects who had difficulty remembering the route itself and some of them may attribute their difficulties to the virtual environment. However, it is probable that the transfer task R to VR further complicates the navigation task because of differences between R and VR (see Chapters 1.10.2 and 2.4.1).

3.3.4 Direction estimation

3.3.4.1 Accuracy

In the first experiment, one of the popular navigation strategies was direction. Some subjects estimated the direction to the goal and based their present route decision on this information (and often also on one or two other strategies). In order to learn about the accuracy of subjects' direction estimations, all subjects of the second experiment were asked to estimate three directions.

Unlike in the experiments done by Sellen (1998), our subjects are unfamiliar to the environment in question. Nevertheless, in my first experiment, the strategy direction leads many subjects successfully to the goal. Due to the structure of the path network, a rough estimation (e.g. "the goal must be half left from the start") is sufficient to reach the goal, though. In order to gain knowledge about all subjects' precise direction estimation abilities, I decided to ask all subjects for several direction estimations. Another question was why half of subjects in the first experiment did not use the direction strategy.

In the first experiment, 49% of subjects indicated they used the navigation strategy direction to retrieve the goal whereas in the second experiment, 75% of subjects managed to give a good direction estimation from the maypole to the start. Assuming that both samples dispose of similar spatial abilities, one additional forth of subjects in the first experiment (75% of subjects like in the second experiment, instead of 49% who actually used the direction strategy in the first experiment) could have used the navigation strategy direction as well, but preferred to use other strategies or did not report to use the direction strategy. Thus, about half of the non-direction strategy users (i.e. about one forth of subjects) in the first experiment were probably not able to estimate the direction from start to maypole whereas the other half of the non-direction strategy users either used the direction strategy, but did not report it or would probably have been able to use it, but did not do so.

Estimating beeline directions to other, non-visible points requires a **cognitive map** of the area, especially in case of directions between two points whose connection is unknown. The experiment results show that more than two thirds are able to estimate the direction from the actual position to the start of a just walked route. Moreover, more than one third is able to estimate the direction to the other route's goal, without knowing about the connection between actual position and goal. So contrary to the assumptions of Siegel & White (1975) that a cognitive map is developped only after plenty of spatial experiences as the last stage of spatial knowledge acquisition (survey knowledge), a notable number of my subjects are able to develop a cognitive map at first contact with the environment.

The best direction estimations are made to the start, the worst to the other route's goal, which was expected (confirms my hypothesis) and can be explained by several factors. First of all, at the moment of estimating directions, the proximity in time of the last visual contact to the start (and to the office) is higher than to the other route's goal.

Furthermore, direction estimations to the start and to the office correlate significantly, but neither of them correlates significantly with estimations to the maypole/statue. The main reason for this may be that the main strategies used to estimate start and office, i.e. mental route and landmark reconstruction, are useful to reconstruct a route that subjects have just walked from the beginning to the actual position. However, these strategies are not sufficient to estimate an unknown connection between two points, like to the other route's goal. Here, subjects have to connect both routes mentally and additionally relate these to the actual position. So, subjects who have not developed a good cognitive map of the campus are probably not successful at estimating the other route's goal. The post-experimental direction estimations of the five experimenters show that even persons living on the campus and disposing of a good cognitive map, estimate the maypole/angel with higher deviations than the start. The difference between start and office mean deviation of direction estimations may result from the different introduction of both points. The office is just the place where the indoor parts of the experiment take place. Experimenter and subject walk from the office through a building to the start. Usually, both are having a chat on this way which absorbs the subject's attention, whereas the start is introduced as the beginning of the experimental task, there the experimenter gives the instructions and thereby both spend a couple of minutes at the start.

3.3.4.2 Positive and negative misalignment

In all conditions, direction estimations form a one peak distribution.

Subjects' estimations from the maypole do not deviate systematically to a specific side, whereas the direction estimations from the statue tend to straighten the angles (see Figure 23). When estimating the maypole straight to the north (omitting the slight eastern component), the mental extension of the path leaving the subject's visual field into the direction of the maypole may be another possible explanation for this result, i.e. subjects probably adapt their estimation to the path alignment. Okabe, Aoki & Hamamoto (1986) found the same systematic error that they explain by the strategy their subjects used (following the route back to the goal).

When estimating the start straight to the west (omitting the northern component), subjects presumably neglect the first two sequences of the route. Estimations to start and maypole form approximately a right angle.

Hence, one part of my results agrees with Popp's (1998) findings that direction estimations deviate systematically (angle straigthening effect), but none of my results confirm a two peak distribution.

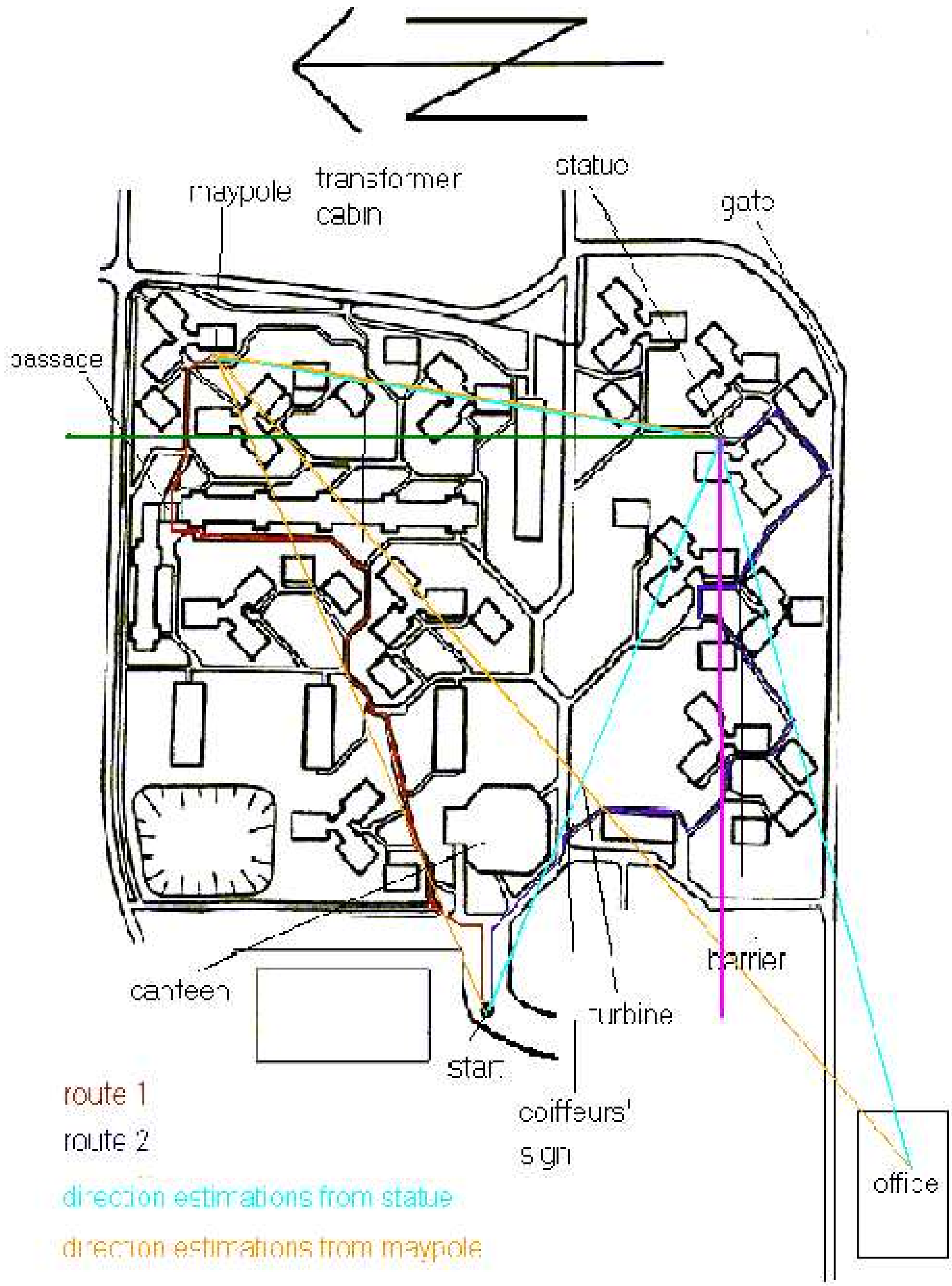

Figure 23: map of the campus, indicated are maypole-route (route 1) and statue-route (route 2), the correct direction estimations from both goals, and the systematically deviated direction estimations (by subjects) from statue to start (pink line) and to maypole (green line)

3.3.4.3 Subjects' evaluations of own direction estimations

Subjective evaluations and objective performances do not match. Similar results were found earlier for distance estimations (first experiment, in Popp, Platzer, Eichner & Schade, 2004) and car driver's navigation (Popp, 1987). According to the above reported results, subjects are unable to evaluate their own spatial knowledge and navigation abilities, specifically in the case of direction and distance estimation, and navigation.

Probably, subjects really do not know about the correct directions and as they do not receive any feedback from the experimenter, it may be difficult to evaluate one's performance. Therefore, subjects may use other evaluation criteria, like general evaluation of their direction estimation abilities or less specifically of their orientation and navigation performance in everyday life. Thereby, the subject's own opinion and feedback they used to receive for their spatial behavior are probably mixed. Indeed, the three subject's evaluations of the respective direction estimations intercorrelate on a medium to high level, whereas the respective evaluations and objective deviations do not correlate.

Further confirmation comes from the finding that direction estimation evaluation correlates significantly with self-evaluations of general orientation and navigation abilities.

3.3.4.4 Direction estimations and navigation performance

I expected good navigators to make good direction estimations and vice versa. Indeed, successful navigators make significantly better direction estimations than unsuccessful navigators. Assuming that good direction estimations require a cognitive map, this cognitive map may be the basis for good direction estimation and navigation performance alike.

3.3.4.5 Strategies used to estimate directions

Subject's direction estimation strategies are based on their knowledge about the distribution of landmarks that are used as points of reference, the area's edges, and the position of the sun. Some strategies also indicate the development of an at least rough cognitive map of the area, like the use of basic directions or namely a survey of the area.

3.3.5 Map task

Another method to conclude on subjects' representation of the area is the map task.

Most subjects are able to indicate once or twice walked paths and the routes' landmarks on a structural map.

Performance doesn't increase with the route description at hand. From this I conclude that subjects either do have a conception of the walked routes within the environment, then they are able to mark routes and landmarks without memory aids, or they are not able to localize the trained routes on the map. This is not due to memory difficulties, because a route description doesn't help them neither.

As unsuccessful subjects (at the map task) use maps less frequently and experience less orientation situations in everyday life, I suppose that first of all, these subjects have difficulties reading maps.

The correlation between time needed for the map task and for navigation in VR is highly significant. The task is somehow similar, because subjects have to find a route, once in VR, once on a map. However, VR presents visual cues of the area in the familiar movie perspective, e.g. buildings that subjects have seen before in R, whereas the map provides a survey of building distribution and path structure, but no landmarks or the objects' appearances. As navigation in VR and the map task follow each other in the experimental sequence, it is also possible that the subject's general performance abilities at the end of this two hour lasting experiment influence both results in the same way.

As expected, subjects who navigated with the route description based on landmarks and thereby focused on landmarks, are able to mark significantly more landmarks than subjects who navigated with the help of route information. This result also shows that training influences spatial perception, i.e. when investigating and evaluating spatial knowledge, we have to consider effects and possibilities stemming from the specific training situation.

Most subjects said that, in their opinion, they had an imagination of the campus, which was egocentric (movie perspective) or allocentric (survey). When navigating, the allocentric group are the only ones to use the strategy direction which confirms my presumption that subjects using the navigation strategy direction dispose of a cognitive map of the area.

Both objective and subjective measures demonstrate that cognitive maps can be developed at first contact with an unfamiliar environment.

3.3.6 Self evaluation

In addition to subjects' self evaluation of their campus imagination, subjects were asked to evaluate their navigation abilities in general.

Most subjects consider themselves to be good or medium navigators and evaluate themselves consistently. Results confirm the hypothesis that there is a high evaluation consistency, that increases if subjects consider their navigation performance in the experiment to be equal to everyday life.

The experiment provides recent navigational experiences that constitute an additional basis for subjects' self evaluation. Nevertheless, actual performance does not induce the majority of subjects to change their self evaluation which may result from the subjects' opinion that navigation performance at the experiment and in everyday life corresponds or from subjects' desire to appear consistent. Indeed, evaluation consistency increases if subjects consider their navigation performance in the experiment to be equal to performance in everyday life. Most subjects confirm this equality which has further implications.

Our aim is to stay as close as possible to everyday life and its common situations, i.e. to provide common tasks encouraging subjects to show usual, thus representative behavior. At the same time, the experiment was planned to ensure objectivity, reliability, and validity. Results show that we succeeded in providing a common context and a situation comparable to everyday life. Therefore, subjects' behavior during the experiment is representative for navigation behavior in everyday life thereby enhancing the external validity of the experiment.

The general problem with subject's self evaluations is the forthrightness of the answers. Although, we positioned the second question for self evaluation about two hours time after the first question and additionally changed the poles of the rating scale, it is possible that some subjects remembered their first answer and, which is important, decided to give the same answer again just in order to appear consistent.

This may be one reason for the result that subjective evaluation measures (both within one person and between subject and experts) are related, but there is no significant relation to the actual, objective performance measures. Self-evaluation and objective performance measures correlate only on a low level.

Thus, my results agree with Popp (1987), i.e. there is a high discrepancy between objective and subjective measures both for car drivers' orientation and navigation in foreign cities and for navigating pedestrians in unfamiliar environments.

Compared to the general evaluation of one's abilities which might be difficult to evaluate (various performances are to be evaluated), the evaluation of a specific and recent performance (here direction estimation performance) should be easier. However, when comparing general evaluation of one's navigation abilities and evaluation of one's performance at a specific task, it results that subjects are better at evaluating general performance than a specific performance, namely direction estimation accuracy. This contradicts my hypothesis that subjects are better at evaluating a specific performance than general performance. Probably, subjects are not good at evaluating their direction estimation performance, because they do not know about its accuracy and do not receive feedback neither. Usually, when navigating people receive feedback about navigation success, e.g. by arriving at the goal in time or other people's feedback for route descriptions, etc.

3.3.7 Cognitive map

In addition to investigating objective performance measures indicating the existence of cognitive maps, I directly asked subjects at the end of the experiment if, in their opinion, they had a cognitive map of the area (the term 'cognitive map' was explained by the experimenter until the subject indicated that he/she understood what the concept 'cognitive map' means). I decided to do so, because I noticed that subjects express concrete ideas of their imagination of the campus. As it arose during the experiment, the question concerning the perspective of the subject's campus conception was introduced only with the 17th subject, i.e. I got the answers of 24 subjects.

90% of asked subjects said that they had an imagination of the campus. Two thirds (66,7%) of subjects dispose of the egocentric perspective, i.e. they can follow the route in their mind like in a movie. One third (33%) are even able to see the area from a bird's-eye view, i.e. they dispose of a cognitive map (allocentric perspective). When navigating, the group disposing of a cognitive map uses the strategy direction significantly more often (t-test: $p=.038$, $df=22$, $r^2=18\%$, $d=.76$). More concretely, they are the only ones (25% of the subjects disposing of a cognitive map) to use the strategy direction, whereas subjects disposing of the egocentric perspective do not use it at all. This confirms my assumption made at the first experiment that a cognitive map is the prerequisite to use the strategy direction. However, the grades received at the map task are slightly, but not significantly better for the 'cognitive map group' ($\bar{x}=2.13$) compared to the 'movie-like perspective group' ($\bar{x}=2.47$). Probably the small number of subjects (n=24) and a small effect prevent significant results here. A study with a larger sample could show more pronounced effects.

Of course, subjective evaluations of experimental subjects may not correspond exactly to the real facts, especially subjects' interpretations of questions may vary and therefore produce different answers. However, my experimenters were trained to explain the terms until the subject signalizes to understand what he means (e.g. by repeating or summarizing the definition the subject him/herself). In addition, the so-called objective measurement methods (e.g. performance measurement) that are used for comparison are also measuring a variable (usually behavior, here map task or direction estimation performance) and conclude from this variable to "real facts". Therefore, I consider subjects' evaluations and behavioral variables to be both methods to conclude on real conditions (here existence of a survey of the campus in the subject's mind) and featuring different advantages and disadvantages.

In theory Chapter 1.6.4, I proposed that the three stages of spatial knowledge (main sequence: landmark, route, and survey knowledge) described by Siegel & White (1975) rather follow each other with regard to their dominance, but do not exclude one another.

Several of my experiments' results confirm this sequence of spatial knowledge dominances. In the following, I cite the corresponding results with regard to the analysis of navigation strategies at the first experiment, direction estimation performance, route description analysis, and map task performance at the second experiment.

The first experiment provided the first indicators that subjects are able to develop route and survey knowledge in a quite unfamiliar environment. Although the subjects in my first experiment had very little training (they walked only once on the route) before searching for the goal of the navigation session, they used strategies based on all three types of spatial knowledge. For example, the navigation strategies route sequences (based on route knowledge) and direction (which is assumed to be based on survey knowledge) lead many subjects successfully to the goal.

At the second experiment, subjects were explicitly asked to estimate directions.

Estimating beeline directions to other, not visible points requires a cognitive map of the area, especially in case of directions between two points whose connection is unknown. The second experiment's results show that more than two thirds are able to estimate the direction from the actual position to the start of a just walked route. Moreover, more than one third is able to estimate the direction to the other route's goal, without knowing about the path connection between actual position and goal.

At the second experiment, subjects also had to make a route description of one route on campus and of one in their neighborhood. Subjects had to describe a familiar and an unfamiliar route in order to compare the effects of route familiarity on route descriptions. According to these stages of dominant spatial knowledge, results confirm a dominance of landmark related classes for unfamiliar routes, whereas in descriptions of familiar routes, there are significantly more route sequences. Thus, when getting to know a new area, people develop particularly, but not exclusively landmark knowledge. With further spatial experiences in this area, i.e. with increasing familiarity, the dominance of spatial knowledge is shifted to route and later to survey knowledge.

Finally, the map task presents objective and subjective confirmation that some subjects do develop a survey of an unfamiliar area at first training. Most subjects are able to indicate routes and landmarks of a once or twice walked path on a very basic structural map. In order to indicate the routes, subjects have to chose from the many paths in the complex path system of the campus. However, there is no symbol or other mark on the map that indicates a landmark's location. When marking the landmarks, the correctly marked routes may help, but subjects need to know where landmarks are located approximately. Therefore, I assume that subjects need at least a rough survey of the campus to indicate routes and landmarks correctly. When asking subjects directly if they had an imagination of the campus, most subjects said that, in their opinion, they had an egocentric (movie perspective) or allocentric (survey) perspective. Subjects indicating to have a movie perspective seem to have developed route knowledge of the campus, and subjects even having an allocentric perspective seem to dispose of survey knowledge. In addition, the allocentric group uses the strategy direction significantly more often which confirms my presumption that subjects disposing of a cognitive map of the area use the navigation strategy direction more often.

3.3.8 Sociodemographic variables

3.3.8.1 Gender

Men and women differ rather on the confidence level than on the performance level. When asked to evaluate their performance, men award themselves better navigation grades and are more sure about their direction estimations than women. However, with regard to performance, there are no significant gender differences. Indeed, women's route descriptions include less redundant sequences and receive tendencially better evaluations from both experts. On the contrary, men give slightly better direction estimations.

As subjective evaluations and objective performance correlate only on a low level, men's high self-evaluations probably result less from previous performance experiences, but rather from common expectations (a man is usually good at navigation).

Contrary to my expectations, women's evaluations do not increase after objectively good performance during the experiment. Probably, the aim for consistent answers overshadows the adaptation to recent performance. In addition, women with medium or negative self-evaluations may not be inclined to change their self-evaluation based on one (differing) experience for several reasons. Women may regard navigation ability as a consistent characteristic which does not change quickly. It is also possible that they are so sure about their negative evaluation, which may be reinforced by common prejudices (women are no good navigators), that one differing experience is not sufficient to change the opinion. Finally, women may attribute their recent success to luck (externally), so "being lucky" once is no reason to change one's evaluation of a supposedly consistent quality.

Comparing men and women of my sample, we have to take into consideration that women have a significantly higher educational level than men. This is relevant as education correlates significantly with exercise (navigation situations) and navigation

performance. Nevertheless, in the first experiment we found the same tendency that women perform better at various navigational tasks that cannot be explained by educational effects, as men and women had similar education background.
My result that women use less redundant sequences coincides with Popp (2000) who had students explore the campus and search for several objects. When asked for remembered landmarks afterwards, male participants named significantly more landmarks than women. Further analysis of these landmarks revealed that women remembered the relevant landmarks, whereas men remembered additionally many task (navigation) irrelevant landmarks. To sum up, men remember and note more details, but women notice the vital aspects.

Contrary to MacFadden, Elias & Saucier (2003) who found that men indicate the point of the compass whereas women indicate landmark and route sequence information, my results show that men and women use the same classes of information to describe a route. The number of subjects in both studies is about the same (40 subjects in my experiment, 44 subjects in the experiment by MacFadden, Elias & Saucier, 2003), thus, the probability that gender differences become significant is similar. However, both studies differ with regard to the training method. In my experiment, subjects learned the route on a guided tour. In the experiment by MacFadden, Elias & Saucier (2003), subjects learned routes on a map, and investigating the learning process, the authors found that men and women scan maps similarly. Furthermore, it is interesting to note that the point of the compass which was the preferred route description class by men in the experiment by MacFadden, Elias & Saucier (2003), was not used by subjects in my experiment. One forth of my subjects describe directions, but do not mention the point of the compass. Therefore, I further conclude that the training method has a pronounced effect on the way subjects describe routes, especially for men.

3.3.8.2 Means of transportation

The means of transportation is related to direction estimation performance. Subjects usually using their car perform better than subjects usually using the local public transportation system perform. Most car drivers quickly develop better cognitive maps than people mainly using other means of transportation.

The latter are navigated by bus-, tram-, subway- or train drivers. When riding by subway which is prevalent in Munich, passengers do not even get a chance to look out of the window and follow the route taken. Thus, a relevant part of public transportation passengers is gaining less navigation experience when moving around. However, asked for the frequency of experienced navigation situations, public transportation passengers do not indicate a lower frequency than car-drivers. This surprising answer may result from the subjective evaluation criteria subjects use to indicate the frequency of experienced navigation situations. Probably subway users consider the use of the public transportation system to be a navigation situation as well. Furthermore, there is a subgroup of six subjects who indicated to use often both the car and the public transportation system, which reduces frequency differences.

Accordingly, even when controlling for frequency of navigation situations, partial correlations between means of transportation (car or public transportation) and direction estimation performance are still significant.

The way of moving through an area significantly influences our perception of it and hence, the acquisition of spatial information (Ruddle, Payne & Jones, 1998; Chance, Gaunet, Beall & Loomis, 1998). The question was if, beyond that, the subject's habit of moving through the environment in a certain way (e.g. by subway or by car) also influences the acquisition of spatial knowledge in another, unfamiliar area even if all subjects move in the same way, they walk. Indeed, subjects often going on foot produce their route descriptions significantly faster and receive significantly better grades for the map task. The experiment's route descriptions aim at pedestrians, so pedestrians dispose of more related experience which may be the major reason for their superiority on this task.

Furthermore, car drivers perform significantly better at estimating directions, subjects usually using the local public transportation system perform significantly worse. As an, at least rough, cognitive map is a prerequisite for direction estimation between two points with unknown connection, this means that most car drivers quickly develop better cognitive maps than public transportation passengers. This result corresponds with Appleyard's (1969) findings who related the subjects' mode of travel to spatial knowledge acquisition, as well. He had subjects draw sketch maps of their home town Guayana and found that subjects usually moving by car mostly produced survey maps, whereas subjects using buses produced less coherent maps. So, travel mode seems to have a remarkable effect on spatial structuring style.

3.3.8.3 Previous experience

Results confirm that the general principle “the amount of exercise is related to performance” can be applied to orientation and navigation. The more often subjects experience orientation situations, the better their performance in orientation related tasks. However, correlations do not provide information about causal relations and having subjects indicate their frequency of orientation situations is a subjective measure, depending on the subject’s definition of “frequent” and further factors, like social desirability, that might influence the answer. Nevertheless and contrary to the evaluation of the quality of their navigation abilities, subjects seem to be able to indicate the frequency of orientation situations, as subjective and objective (performance) measures correlate significantly.

4. Conclusions

4.1 Sequences of spatial knowledge acquisition

What kind of spatial knowledge do people acquire when moving in an unfamiliar environment?

The results of my experiments do not confirm the successiveness of three stages of spatial knowledge as supposed by Siegel & White (1975), but demonstrate that the proposed stages are rather types of spatial knowledge whose use depends on various factors (e.g. personal preferences and abilities, environment, training, also see factors influencing navigation performance in Figure 3).

I proposed that the three stages of spatial knowledge (main sequence: landmark, route, and survey knowledge) rather follow each other with regard to their dominance, but do not exclude one another.

Several of my experiments' results confirm this sequence of spatial knowledge dominances and demonstrate that not only landmark knowledge, but also route and survey knowledge may be developed from the very first contact with an environment..

In the following, I summarize the corresponding results with regard to the analysis of navigation strategies at the first experiment, direction estimation performance and map task performance at the second experiment.

In both experiments, subjects were new to the environment and had only little training possibilities to acquire spatial knowledge about it.

Nevertheless, results of both methods used in the first experiment, thinking aloud and strategy interview, show that the three most frequent strategies are based on route and survey knowledge. The more detailed discussion can be found in Chapter 3.3.7.

In addition, results of the direction estimation task in the second experiment indicate that half of subjects have developed survey knowledge of the campus after having walked on two routes within campus.

This was confirmed at the map task. Most subjects were able to mark both routes and remarkable landmarks on structural maps providing a complex path system and some buildings. Almost all subjects of the second experiment said that they had an imagination of the campus. One third even say that they are able to see the area from a bird's-eye view, i.e. they dispose of a cognitive map (allocentric perspective). Indeed, when navigating, subjects in this group are the only ones to use the strategy direction.

4.2 Measurement methods for cognitive maps

With regard to measurement methods for cognitive maps, experiences in both experiments show that the investigation of navigation strategies, direction estimations and a map task, are suitable instruments to apprehend the existence of a cognitive map. Navigation strategies can be recorded by a structured version of the thinking aloud method and additionally by a strategy interview after navigation.

The direction estimation method is a good method to test subjects' orientation and survey knowledge of an area. The method is easily applicable once some spatial knowledge of an area has been acquired. A small number of direction estimations takes only a few minutes, can be made with a simple device (e.g. see our device in Chapter 3.1.8), and produces exact quantitative results. Estimating beeline directions to other, not visible points requires a cognitive map of the area, especially in case of directions between two points whose connection is unknown.

An important part of cognitive maps are landmarks.

4.3 Landmarks

What are the remembered details when exploring an unfamiliar environment?

Landmarks are important for navigation and therefore a popular research object. My results confirm both the popularity of landmark use and the account of landmarks for navigation success and route description quality. Landmarks are used within the scope of various important navigation and route description strategies. Thereby, landmarks are the most often used strategy in both experiments. A comparison of two kinds of route descriptions shows that a route description based on landmarks enables subjects to significantly faster navigation (on one of the tested routes) than a route description based on route sequences.

Landmarks can have a variety of useful functions: landmarks structure space, sub serve for navigation, and may be a piece of art and a basis of identity with a district;

Chapter 1.4 of this work explains the definitions, characteristics and types of landmarks that are later confirmed by my results. i.e. the chosen landmarks actually feature most of those characteristics. This knowledge about landmarks enables us to identify or create landmarks according to the described characteristics.

If we could plan the ideal landmark distribution in a new area, every landmark characteristic should be used once. Planning additional landmarks in an existing area, we should check which characteristics are already used and try to apply another one, e.g. if many objects stand out by size, we should create one standing out by shape or decorative details.

I further suggest to position new landmarks or to transform existing objects into landmarks (according to the noted landmark characteristics) in areas lacking landmarks and identity providing objects. If possible, these landmarks should be positioned at navigational decision points or nodes (which inversely increases the probability to be perceived as landmark).

When deciding on the details to be displayed in a virtual environment, it should be considered that even movable objects, which do not fit the majority of landmark definitions, may be frequently used landmarks in R and therefore should not be neglected in VR. It is important to provide enough relevant landmarks in virtual environments in order to make navigation process and success comparable to real environments. Especially when investigating which objects in an environment qualify for landmark it should be considered that the number of potential landmarks provided influences the subjects' landmark choice criteria. If there are less landmarks provided, as it is often the case in VR, the available landmarks are used more frequently. Like this, the importance of these few available landmarks may be overestimated.
The following sections provide more suggestions for the conception and use of virtual environments.

4.4 Virtual environments

4.4.1 Virtual environments as a research method in spatial cognition

4.4.1.1Transfer of spatial knowledge between reality and virtual reality

Virtual environments are already used frequently in research and practice. However, it remained unclear to what extent human spatial behavior in real and virtual environments is comparable and if spatial knowledge acquired in virtual reality can be transferred to reality, and vice versa. In my first experiment, I directly compared navigation behavior in a real and virtual version of the same environment.

To sum up our results, virtual realities are comparable to reality concerning the navigation process, but not with regard to performance.
Transfer of spatial knowledge between reality and virtual reality is possible in principle, but with different levels of performance. The congruence between training and test environment leads to higher performance in the real training and test environment.
The navigation process is comparable with respect to its strategies in both environments. Analysis of strategies shows that the virtual environment does not reduce the number of possible strategies and that subjects use the same strategies than in R. These results have important consequences for navigation research.
Experiments aimed at investigating the human navigation process can be performed with high quality virtual environments without restricting the representativeness of results to virtual realities. With regard to the navigation process, external validity is retained.
Thus, virtual realities are a useful and valid tool to investigate navigation processes. However, if performance is focused, transfer difficulties should be taken into account.

It would be desirable to quantify the behavioral differences between real and virtual environments and to develop a function to bridge this difference, e.g. a certain performance in VR equals performance in R once it is improved to a certain degree. However, it will be hard to develop a good function that is applicable to different kinds of spatial knowledge acquisition methods and to various performance measurement methods which potentially moderate the spatial knowledge transfer process.

4.4.1.2 The impact of sociodemographic factors on navigation performance

The impact of sociodemographic factors, like field dependence, gender and practice is low, but statistically significant. The frequency of navigation practice as well as the EFT are related to navigation performance. However, correlations with navigation performance are low and the investigation of gender differences at the EFT and at navigation performance reveal that women's repeated lower results at paper-and-

pencil-tests concerning spatial cognition or particularly field dependence (EFT) do not imply lower practical performance at navigation tasks.
On the practical level, the significant correlation between navigation practice and navigation performance could mean that navigation skills can be trained, i.e. people could improve their navigation abilities by approaching navigation situations in unfamiliar areas instead of avoiding self-reliant movements. But it is also possible that (genetically caused) good navigation abilities foster practice, because these people receive positive feedback when navigating and therefore continue doing it.

Effect sizes of significant differences in this experiment indicate a reasonable effect of the independent variables. However, a single independent variable explains only 10 to 20% of the variance of navigation performance. Thus, there is a large number of factors influencing complex human behavior, like orientation and navigation.

4.4.1.3 Consequences for the configuration of VR

Before deciding on the right configuration and complexity of virtual environments, it is important to decide about its intended purpose and the supposed users' time and training possibilities.
If users dispose of little interaction time and thereby little training possibilities in the virtual environment, geometrically simple structures of road and path network and unequivocal landmarks facilitate navigation.
However, when focusing on complex navigation strategies, when investigating the navigation process and performance that is comparable to navigation in real environments, and/or when comparing real and virtual environments, more complex and detailed environments should be used.

Virtual environments can be created without and with real basis.
If a prototypic reality should be created without real basis, cultural knowledge (e.g. town hall in the center) should be considered to facilitate navigation
Landmarks should be integrated into virtual environments and be placed at decision points: First, routes with landmarks are learnt significantly faster (Jansen-Osmann 1998). Second, landmarks indicating a correct turning can be localized significantly

better (than those landmarks indicating a wrong turning or no turning) (Cohen & Schuepfer,1980).

Virtual environments with real basis should include the respective path and road network as well as landmarks.

With regard to the configuration of VR, we should continue to aim at improving the virtual environments, both at the technical and at the psychological scope. The last-mentioned means to investigate the factors which influence the presence effect of virtual realities with regard to spatial orientation and to learn about the essential navigational features that should be integrated in a virtual environment in order to provoke spatial behavior that is similar to navigation in real environments. This knowledge about the relevant cues for navigation will help to enhance the quality of the virtual environment and reduce financial and time efforts by purposeful entry of the actually relevant features.

Although the virtual representation of our vision dome features outstanding quality, the virtual environment and the movement in it are unfamiliar to most subjects. Therefore, subjects should be given some time to get used to the virtual character. Otherwise, attention might lack for orientation and navigation and thereby affect performance.

The visual cues our vision dome provides are similar to those in R. So far, most virtual reality investigations are limited to the presentation of visual cues, although spatial cognition is based on further sensory input, like visual, auditory, tactile, proprioceptive, and vestibular cues (Riecke, 1998).

Considering the effort and costs to provide additional sensual interaction possibilities, it does make sense to investigate if and how behavior changes in different interaction conditions. With it, we can conclude what kind of sensory information and what level of interaction we need for a certain project.

According to Downs & Stea (1982, p.298), active exploration and free choice of route foster spatial learning. By contrast, Wilson, Foreman, Gillett & Stanton (1997) found in two experiments that neither psychological nor physical activity influenced the acquisition of spatial knowledge.

With regard to training in both environments, I think that it is impossible to realize totally free exploration conditions in an experiment without losing control and thus creating unstandardized situations for the subjects. A certain level of control of training conditions is the prerequisite for valid performance measurements afterwards. Thus, the right level of activity depends on the aim of VR use.
I decided on a guided tour as training phase. As I am interested in spatial behaviour the way it is shown in everyday life, both experiments provide a common situation:
In the first experiment, someone is fetched up at the station by a friend, both walk to the friend's home; one week later, the person arrives at the station again and is expected to find the way by him/herself;
In the second experiment, someone walks on a route and gives a route description afterwards. Later, the person receives a route description and tries to find the described route.

The results of my experiment are representative for common training and navigation situations in urban environments, but probably not for "free choice of route" training situations.

Siegel & White (1975) relate landmarks mainly to visual cues and routes to sensorimotor cues. This raises the question if the kind of provided cues is related to navigation strategies used to navigate on this route afterwards. For example, do subjects walking on the route during the training phase, develop better route knowledge and use the strategy route sequences more often than subjects standing still during the training?
One aspect is that movement in VR is more passive than in R, which may make navigation more difficult. To allow for more active exploration in VR, a treadmill is currently installed to walk through our virtual campus. Like this, motoric cues can be provided at future experiments and thereby improve the next experiments' conditions. This natural movement possibility is expected to improve navigation results in VR and will help to clarify what level of motory interaction with the virtual environment we actually need. The treadmill will enable us to clarify these questions in the next experiment. The visual cues remain the same while the factor walking or not is changed.

However, other sensory cues that may function as or add up to the perception of a landmark are not considered yet.

4.4.2 Applications for virtual environments beyond spatial cognition research

There are various fields of application for virtual environments (beyond spatial cognition research). Both the number of possible applications for virtual reality technology and its quality are increasing.

Applications for VR without real basis are for example the project planning for buildings, parks, or entire districts. The virtual representations of the planned objects help to evalute the construction plan with regard to various criteria, e.g. orientation facility, before starting construction work; In addition, different plans can be compared by investigating the relevant performance criteria when moving through the virtual environment.

Applications for VR with real basis are numerous.
VR is ideal for the training of operators performing tasks in dangerous or hazardous environments, for example in the fields of aviation, medicine, and nuclear energy. The trainee can be exposed to life-threatening scenarios, under a safe and controlled environment. He can start practicing the procedure in virtual reality, before graduating to reality-based training.
When using virtual realities as a training tool, it should be considered that spatial knowledge acquisition (and transfer possibilities to R) is not on the same level than training in R. It would be interesting to research whether further training with the tool VR can improve transfer performance. In cases where training in R is very difficult or not possible at all, training in VR is surely a good alternative to pure theory or map studies, as it enables to much better performance than without training (Popp, 1995).
At least after the introduction, the trainee should be able to train by interacting with the virtual environment.

VR is also an ideal tool to train operators for the operation of expensive equipment or equipment with a high running cost. Training in VR safeguards the equipment and

saves energy. Furthermore, VR training is possible without taking the equipment out of production.
In addition, VR training could prepare people for ‘single opportunity' tasks, for example a lunar landing or the repair of a communications satellite (Fifth Dimension Technologies).

Two other fields of application are ergonomics and medicine.
In ergonomics, systems like MAVE (Mock-up for Virtual Ergonomic Analyses) enable product designers to evaluate the functional prototype before constructing real models.
In medicine, virtual representations of patients provide navigation training and facilitation in environments that are difficult to access, e.g. the human body during endoscopy surgery, and enable doctors to ask a distant specialist’s advice. Thereto the distant doctor can examine the patient at places differing from the own position. Furthermore, immersive VR representations featuring haptic feedback enable medical students and professionals to train difficult procedures in a risk-free, virtual environment. Augmented reality technology can support surgeries by projecting a transparent display providing useful information on the patient’s body.
For further information on this topic, please see Deml (2004).

There are various possible applications in tourism, as well. Virtual reconstructions of past worlds can enable us to e.g. walk around in 17th century Florence or in one of its present museums while being at another place of the world. Augmented reality can expand a visitor’s field of vision by virtually completing destroyed buildings and objects and by adding interesting information.

The next topic investigated is rather related to everyday life: giving and using route descriptions;

4.5 Route descriptions

Subjects navigated on a route with a route description prepared by the experimenters and produced their own route description of a further route.

The results of my second experiment and of Kalbow’s study (1993) show that ordinary route descriptions (i.e. spontaneous descriptions given by lay-persons) do not constitute a good navigation aid.
Contrary to that, the 100% success rate of the navigation task with the prepared route descriptions (all subjects reached the goal within the scheduled time) shows that it is possible to enable successful navigations by providing well prepared and defined route descriptions (second experiment).

If we are spontaneously asked for the way in the street, we usually don’t have the time to give a well prepared and defined route description. But if route descriptions are created for common use, a generally comprehensible description should be prepared.
Criteria of good route descriptions are based on the chosen route and its description. We should chose an efficient and agreeable route considering the navigator’s means of transportation. The description itself should be precise, easy to remember, and omit redundant specifications (i.e. unnecessary details). The number of chunks to be remembered should be reduced as much as possible and to a maximum of 7+-2 chunks (Miller, 1956) - as long as we can still ensure the sufficient description of all crucial sequences.
The need for additional information depends on the aim of the description and on the hearer’s expectations. In case of written information, like e.g. guidebooks, it may not be possible to satisfy all potential readers. The author can try to find a happy medium between a short and a detailed description, provide both or mark additional information (e.g. by putting it into brackets).

The general question is not only how much, but also what kind of navigation information should be provided. What kind of knowledge should navigators gain?
Theoretically, survey knowledge allows for the most flexible and least fault-prone navigation. However, my experiments show that its acquisition requires some previous navigation exercise (here indicated by a high frequency of orientation and navigation situations providing relevant experiences) and/or a sufficient number of adequate possibilities to get to know the environment in question.

In addition to these prerequisites, not everybody is able to and wants to navigate on the basis of survey knowledge. Some people prefer navigating with landmarks and/or routes. Theoretical pretensions (survey knowledge as the most comprehensive knowledge which provides the highest amount of autonomy) on the one hand and practically meaningful possibilities and individual preferences on the other hand are conflicting.

My experimental results show interindividually differing preferences for navigation strategies. Furthermore, different strategies lead successfully to the goal, i.e. there isn't just one way of doing it. I think that strategies are adapted to a person's abilities and to the environment in question.

Contrary to general beliefs, a map is not a good possibility to present spatial knowledge. My second experiment shows that many people take a long time to comprehend a map, some people are not able to read a map at all.

Reading a map is further complicated if the navigator is driving a car. In the case of longer or more complicated routes, a driver that is unfamiliar with the place has to look at the map repeatedly in order to stay on the right track. However, looking at a map is quite difficult when driving a car because of the unhandy size of most maps and the need to orientate oneself on the map before being able to draw conclusions about the route to continue. Especially in the case of more complex city maps, the time usually available to study the map (a few seconds maximum) is not sufficient to make adequate route decisions. A study by Färber, Popp & Schmitz (1992) comparing car driver navigation based on a city map, co-driver assistence, and a navigation system, found that drivers' performance (with regard to traffic safety) is worst when navigating with the city map.

4.6 New research topic: Attributions of navigation success

With regard to car driver navigation, Popp (1987) showed that subjective evaluations and objective performances do not match. Similar results were found for distance estimations (Popp, Platzer, Eichner & Schade, 2004).

When searching for the reasons for the difference between subjective evaluation and objective performance, I discussed the attributions of failure and success.

Causal attributions for navigation success or failure are an interesting topic that could be included easily in a new navigation experiment. Some important aspects are internal and external attribution, gender differences, and the congruence of self-evaluation and performance. Knowledge about the subjects' attributions could help to understand the reasons for their subjective evaluations.

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