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The Influence of Active and Passive Navigation on Spatial Memory of Drivers and Co-Drivers

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1. Introduction

Imagine you have moved to a new city. In the beginning, you will know barely more places than the place you live and the place you work at. You will need to identify and remember the route from your living place to your working place. Within the next days, you have to locate and memorize the routes to a number of additional places, for example a supermarket and the post office. Another couple of days later, you want to go to the supermarket on your way home from work, and you put these places into reference to each other.

This example shows that route learning is an integral part of human existence. Every day, people need to move from one place to another for countless reasons, including work, leisure activities, or organizing provisions for everyday life. Obviously, everyday life becomes incredibly complicated if one is not thoroughly able to locate and reach these places. Thus, a proper encoding of spatial information is required.

Consequently, the mechanisms and methods people use to structure and memorize their surrounding environment have attracted psychological research since the first half of the 20th century. Fundamental work on spatial cognition was achieved by Tolman (1948), who developed the concept of a cognitive map as a mental representation of the environment. In the following decades, other essential differentiations were made, for example Siegel and White's (1975) classic distinction into landmark knowledge, route knowledge, and survey knowledge (see section 2.1.1 for further details). The distinction into these levels of spatial knowledge is still used in most recent studies on spatial cognition, although some of the original conceptions, for example the idea of a hierarchical spatial learning process starting with landmark via route to survey knowledge, have been challenged by more recent frameworks of spatial cognition (e.g., Montello, 1998).

However, spatial learning is not only determined by the properties of an environment, but also by how it is experienced. To continue the initial example, a colleague at work might describe you the way to a certain shop. His descriptions become confusing, thus he draws you a sketch map. You eventually find the shop. On the next day, this colleague invites you to his favorite bar after work. While talking, you follow him through a couple of streets and find yourself in the bar without remembering how you got there exactly. Although you walked the way to both locations, it appears likely that you are going to remember the route to the shop, whereas you might have more trouble to locate the bar.

Thus, there are numerous ways to receive and encode spatial information, which may be more or less suitable to memorize a route in specific situations. A number of influential studies aimed to identify the optimal conditions for spatial learning and compared for example spatial knowledge after participants either studied maps or navigated through an environment (Golledge, Dougherty, & Bell, 1995; Thorndyke & Hayes-Roth, 1982). More recent approaches extended this comparison to electronic route guidance systems (Krüger, Aslan, & Zimmer, 2004; Münzer, Zimmer, Schwalm, Baus, & Aslan, 2006; Willis, Hölscher, Wilbertz, & Li, 2009). Some early studies analyzed the effects of different modes of transportation on spatial knowledge: Appleyard (1970) analyzed how people mentally structure a city. Major differences appeared (among others factors) for the mode of transportation. People who commuted with their own car developed a more map-like and exact representation of a city than people who used public transport. Herman, Kolker, and Shaw (1982) compared spatial memory of children for an environment they had encountered in a riding, a walking, and a standing study condition (also see Cohen & Cohen, 1985, for a general overview on the role of activity in spatial cognition).

The most common situation where such different transport modalities can have an impact on people's spatial learning in modern life is car-driving, with the driver controlling the car and an observing co-driver. Is there a difference in spatial learning between drivers and co-drivers? The initial example shall illustrate this question. You and your colleague decide to join a car to go to a meeting at another place in the city. If you want to remember this route, is it advantageous that you – rather than your colleague – are the driver and he directs you where to go? Or would it be better if he drives, and you focus on memorizing the tour?

Most people claim that being the driver is essential for successful route learning and inherently superior to being the co-driver. However, the empirical evidence for this assumption is scarce. There are both studies where people were exposed to a pre-selected route (resembling the role of a passive co-driver, e.g., Herman et al., 1982; Tom & Denis, 2004), or where people were in control of their movement (resembling the role of a driver, e.g., Lee & Cheng, 2008), but few studies which directly compared spatial learning of drivers and co-drivers.

First evidence for the assumption that driving is not as genuinely superior to co-driving as generally believed can be derived from research on the effects of electronic route guidance systems: it has been questioned whether such systems benefit spatial learning (e.g., Krüger et al., 2004; Willis et al., 2009), whereas they benefit driving safety (e.g., Lee & Cheng, 2008). This meets the subjective impression of many drivers who state that using a route guidance system leads to little memorization of spatial information. This implies that it may not be the physical control of a vehicle itself that guarantees the encoding of spatial information.

Findings of two other research fields can be related to spatial learning of drivers and co-drivers, namely research on action memory and on active navigation. Short introductions into these fields are provided below, followed by a description of the aims and general hypotheses of this thesis.

1.1 Implications of Action Memory Research

The theoretical underpinnings of this thesis originate in research on action memory, a research field that deals with the comparison of different study conditions: Classic theories of action memory would suggest that driving (as an instance of enactment) is the optimal way of encoding (Nilsson & Cohen, 1988), superior to learning by co-driving (as an instance of observation) or verbal learning[1].

A prominent theory reasoned that the so-called enactment effect originates in the additional motor code provided by the execution of an action (Engelkamp, 1998). A first connection of action memory theory with active navigation research based on the motor code hypothesis was achieved by Brooks, Attree, Rose, Clifford, and Leadbetter (1999). The authors argued that – comparable to the robust advantage of enactment of action phrases over

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[1] One may argue that there are fundamental differences between the enactment or observation of simple action phrases (e.g., “clap your hands”, “break a match”) and a driver/co-driver situation: All motor tasks involved in driving a car or a tandem bike (such as turning the handlebar or shifting gears at a turn) are motorically similar and repetitive compared to action phrases used in action memory research, and do not involve distinctive actions connected to a route (Stevens, 2005). However, many real-life activities (e.g., binding a knot) consist of such rather indistinct and motorically repetitive series of actions. The motor tasks involved in driving a tandem bike also resemble a research line that compared memory for simple movement patterns (e.g. move left; move right) after enacting a sequence of movements during the study phase or observing the experimenter’s enactment, with comparable recall after the two study conditions (see Helstrup, 2005, for an overview). Thus, we think connecting action memory research with that on active navigation can be fruitful.

verbal learning (e.g., Cohen, 1981; Engelkamp, 1998; Engelkamp & Krumnacker, 1980) – using a joystick to move through a virtual environment should result in better spatial learning than observing this movement. They report the expected advantage in some, but not all spatial knowledge tasks applied in their experiments

The theoretical framework of the study by Brooks and colleagues (1999) is built upon findings that compare enactment with verbal learning. However, it can be argued that the study situation in their experiments resembles more closely to a comparison of enactment and observation. The empirical evidence for the respective comparison in action memory research is rather ambiguous: Although a number of studies on action memory demonstrated better recall after enactment compared to observation (e.g., Golly-Häring & Engelkamp, 2003), the majority of findings (e.g., Engelkamp & Dehn, 2000; Helstrup, 2005; Steffens, 2007) suggest that enactment and observation lead to similar recall performance (see McDaniel & Bugg, 2008, for a review). Recent frameworks of action memory theory also challenge the importance of motor information provided by enactment. They put more stress on the idea that the crucial mechanism provoking the enactment effect is semantic elaboration of the study materials (e.g., Knopf, Mack, Lenel, & Ferrante, 2005; Kormi-Nouri, 1995; Steffens, Buchner, Wender, & Decker, 2007), and that information processing during enactment is tied by the task demands of enactment (e.g., Steffens, Buchner, & Wender, 2003). Thus, the assumption that driving (as an instance of enactment) leads to superior spatial learning as compared to co-driving (as an instance of observation) due to the activities involved in maneuvering a vehicle is put into question. Transferred to route learning, this implies that spatial learning of drivers and co-drivers could be comparable if active elaboration of spatial information (e.g., by being involved in navigation) is assured.

1.2 Findings of Active Navigation Research

The two last decades saw a rapid development of computer technologies, which allowed the use of virtual environments for spatial cognition research. Virtual environments are an attractive tool in this line of research as they allow a comprehensive control of environmental specifics and measurements. Spatial learning in virtual environments also appears comparable to real environments in most respects (e.g., Ruddle, Payne, & Jones, 1997; Waller, 2000; Wilson, Foreman, Gillett, & Stanton, 1997). Comparable to research on spatial learning in real environments, participants were either allowed to move self-contained and free in an virtual environment (e.g., Foo, Warren, Duchon, & Tarr, 2005; Newman et al., 2007; Ruddle et al., 1997; Stankiewicz & Kalia, 2007) or they were required to observe the movement through the environment passively due to practical limitations and in order to assure constant exposure of all participants (e.g., Shelton & McNamara, 2004). However, a number of studies focused on the very comparison of self-contained and observed movement under the label of active navigation. Péruch, Vercher, and Gauthier (1995) were some of the first who claimed that the more active navigation of free movement could provide advantages as compared to a more passive, observing study condition. The authors reported superior way-finding performance of participants who controlled their movement. Contradicting evidence was found shortly after by Wilson and colleagues (1997): they found no advantages of physically or psychologically active participants over passive participants in the ability to point to landmarks that were not directly visible and the ability to draw a map of the environment. In the following years, the findings on active navigation remained inconsistent. Several studies support the idea of a learning advantage of active over passive navigation (e.g., Buchner & Jansen-Osmann, 2008; Hahm et al., 2007; Wallet, Sauzéon, Rodrigues, & N'Kaoua, 2008), but a similar number of studies found few if any differences (e.g., Cutmore, Hine, Maberly, Langford, & Hawgood, 2000; Gaunet, Vidal, Kemeny, & Berthoz, 2001; Rossano & Reardon, 1999; Wilson, 1999). (A detailed discussion of the inconsistencies in active navigation research is provided in section 2.1.) One factor that appears central to active navigation is the degree of decision control in navigation. A number of studies suggest that the execution of movement may be less important than the decision about this movement (Carassa, Geminiani, Morganti, & Varotto, 2002; Farrell et al., 2003; Wilson et al., 1997). Applied on a driver/co-driver situation, this implies that it is not the physical control of the vehicle that determines spatial learning, but the navigational control of where to move. In most situations, a driver controls both the physical movement and the navigational decisions. However, a driver may depend on the navigational decisions of someone else (i.e., the co-driver), thus being in control of movement only. By implication, if drivers appear to learn routes easily, this may be due to a frequent confound with the control of navigation rather than a genuine advantage over co-drivers. Following this reasoning, co-drivers who control navigation may show comparable or better spatial learning than drivers.

1.3 Outline of the Dissertation

The main aim of this researched can be summarized in the question “Is driving a vehicle genuinely advantageous for spatial learning as compared to co-driving this vehicle?”

Research on action memory and active navigation suggests that this is not necessarily the case. Driving may be confounded with other factors that benefit spatial learning. Thus, the assumed advantage of drivers over co-drivers may not be inherent to driving, but depend on confounds with other factors. Previous studies on active navigation discussed several factors as relevant for active navigation. However, definitions and conceptualizations of active navigation vary between different studies, resulting in inconsistent findings. A systematic comparison of the factors most important in active navigation has not been made yet. Moreover, these existing studies are limited to virtual environments and transfer performance from virtual to real environments. Thus, it is also unclear whether the concepts of active navigation do apply in a driver/co-driver situation.

Consequently, the first aim of this thesis is a specification of active navigation (Chapter 2). A detailed discussion of the current state of active navigation is provided. Three experiments (Experiment 1-3) attempt to systematically identify factors relevant for spatial learning in counterbalanced designs, in order to clarify how these factors interact and affect different levels of spatial knowledge. Experiment 1-3 use virtual environments, in line with the majority of active navigation research. The main hypothesis is that controlling movement (i.e., driving) is not genuinely advantageous in spatial learning as compared to the observation of this movement (i.e., co-driving), but that eventual advantages depend on other factors. If these factors are provided for co-drivers, it can be expected that co-drivers are either able to compensate eventual disadvantages, or that differences between drivers and co-drivers disappear in general.

Rather surprisingly, an attempt to manipulate and study effects of active navigation in a real environment has not been made yet. Thus, the aim of a second series of experiments (Experiment 4-6, Chapter 3) is to apply the findings of Chapter 2 to a real environment in order to test the ecological validity of active navigation research in general, and specifically the validity of the conclusions of the first series of experiments. Using a real car appears impractical for a number of methodological reasons and practical limitations. Using a tandem bike provides the advantages of real locomotion in real large-scale environments with identical exposure of drivers on the front seat and co-drivers on the back seat. If the findings of active navigation research are also valid in real environments, the findings can expect to be comparable to the findings of Series 1.

Chapter 4 aims to integrate findings of both series of experiments and discusses potential limitations as well as future directions before presenting a final conclusion.

2. A Comparison of Route Learning after Self-Contained and Observed Movement in Virtual Environments: Effects of Intention, Instruction Specificity, and Decision Control

2.1 Introduction

One common way to get to know a new route in modern times is driving or co-driving a vehicle. Given this situation, people often claim that it is easier for them to memorize a route when driving (i.e., when controlling movement) instead of co-driving (i.e., when observing this movement). This claim is reflected in research on active navigation. Researchers in this field emphasize the beneficial impact of active physiological and psychological involvement for spatial learning. However, the empirical findings are inconsistent, with several studies in support and others in contradiction of a supposed advantage of active over passive navigation. The diverging findings in active navigation research could be explained by considering the different conceptualizations of active navigation. For example, whereas some comparisons of active versus passive navigation focused on a manipulation of movement control, others comprised elements of instruction specificity or decision control as well. Mirroring a real driver/co-driver situation, we consider movement control (i.e., self-contained vs. observed movement) as a central factor in active navigation. However, movement control can be confounded with other factors relevant for spatial learning. The aim of the present three experiments is disentangling theses factors. In order to test whether a potential advantage of self-contained movement over observed movement is reduced, enhanced, or unaffected by other factors, the present research aims to independently manipulate movement control in addition to intentional learning (Experiment 1), instruction specificity, instruction control (Experiment 2), and decision control (Experiment 3). Following an overview of active navigation research, we review the evidence on each of these factors in turn.

2.1.1 Active Navigation

Central to active navigation research is the idea that the active, self-directed, and free exploration of an environment enables superior spatial learning compared to a more passive, observing encounter of the same environment (for instance, by watching a video clip). This idea has been studied almost exclusively in virtual environments, as the rapid development of computer technology enabled research on spatial learning in semi-realistic, three-dimensional virtual environments. Virtual environments are an attractive tool in this line of research, as they allow a comprehensive control of environmental specifics and measurements, with spatial learning being comparable to that in real environments in most respects (see Wilson et al., 1997, for an overview). However, whereas several studies support the idea of a learning advantage of active over passive navigation (e.g., Carassa et al., 2002; Hahm et al., 2007; Péruch et al., 1995; Wallet et al., 2008), this assumption has been questioned by a similar number of studies that found few if any differences (e.g., Gaunet et al., 2001; Wilson, 1999; Wilson et al., 1997). The contradictory findings may result from different definitions and experimental conceptualizations of active navigation (see Farrell et al., 2003; Péruch & Wilson, 2004). For example, whereas in some studies active navigation refers to movement control (e.g., Wallet et al., 2008), other studies emphasize that active navigation must involve decision control (e.g., Farrell et al., 2003). Other factors have been discussed as potential confounds in active navigation research as well (e.g., learning intention, see Wilson et al., 1997). Thus, if driving a vehicle (i.e., self-contained movement in a virtual environment) leads to apparently better route learning than co-driving (i.e., observed movement), this may be due to confounds of movement control with such factors.

The ambiguity of findings in active navigation research is amplified by the variety of spatial-knowledge tests applied (see Brooks et al., 1999; Péruch & Wilson, 2004, for further discussions). Commonly, three types of spatial knowledge are differentiated when assessing spatial knowledge (as first introduced by Siegel & White, 1975). Landmark knowledge refers to information about distinctive and stable features of the environment. Route knowledge refers to information about the order of appearance of such landmarks, and information about turns on a given route. Survey knowledge provides information about spatial relations of features in the environment in the form of a cognitive map that includes many features of a real map such as Euclidian properties of physical space (e.g., Thorndyke & Hayes-Roth, 1982). It can be concluded from a recent review of studies comparing effects of active and passive navigation (Wallet et al., 2008) that active navigation provides no advantage in classic survey knowledge tasks – such as pointing towards landmarks that are out of sight and sketching maps of the environment (and in many cases active navigation does not lead to advantages in landmark knowledge tasks such as landmark recognition). However, the majority of studies that used way-finding tasks as more applied tests of survey knowledge report superior performance after active navigation (including Wallet et al., 2008). Taken together, the type of spatial knowledge test applied influences whether active navigation appears superior to passive navigation. Thus, in the experiments below we use a spectrum of the most common spatial knowledge tests.

2.1.2 Movement Control, Decision Control, and Instruction Control

It can be argued that the difference between participants who actively explore a virtual environment and participants who passively watch a yoked video clip is not physiological activity, but mainly psychological activity. In other words, movement control and decision control are confounded (e.g., Péruch et al., 1995). In a clever experimental design, Wilson and colleagues (1997) disentangled movement control from decision control. Resembling a driver/co-driver situation, one participant controlled movement with computer keys (i.e., being physiologically active), the other participant observed this movement (i.e., being physiologically passive). Additionally, one of them decided where to move (i.e., being psychologically active), the other did not make decisions (i.e., being psychologically passive). In contrast to their expectations, the authors found neither an effect of physiological activity nor of psychological activity. However, the authors' choice of task (pointing and map drawing) may have contributed to this result, because these tests seem to be rather insensitive to manipulations of active navigation (see also Wallet et al., 2008).

Subsequent studies that did not use completely counterbalanced designs were more successful in providing evidence that mere control of movement is less central to spatial learning than control of decisions. In a study where all participants controlled their movement and active navigation was manipulated by either providing active decision control through free exploration, or requiring the participant to passively follow a specific course, a way-finding advantage of active decision control was reported (Carassa et al., 2002). Similarly, participants who had free control over movement but saw a red line on the floor indicating the optimal route through the virtual equivalent of a real environment showed the same transfer performance to the real environment as participants who passively watched a video clip presenting the same route through the maze (Farrell et al., 2003). Only participants who were allowed to explore the virtual maze freely without the red line were superior to those in the other conditions. Thus, not the control of one's own movement, but active decision-making about the route led to better transfer. In conclusion, there is evidence that controlling the decision where to move is more important than the execution of this movement. More specifically, active decision control could be more central to spatial learning in active navigation than active movement control, but so far the evidence is limited.

Another aspect of control has yet to be included in active navigation research, namely instruction control. In many real world situations, navigating a route does not involve any actual decision, but rather complying with a series of navigational instructions. Even without decision-making, studying the instructions may provide a spatial learning benefit: studying the instructions may increase the probability that the spatial information provided in the instructions is transferred and connected to spatial properties of the environment. In a driver/co-driver situation, it is not necessarily the driver who studies the instructions. Instead, it is possible that co-drivers read these instructions to the drivers in order to enable the latter to focus on driving. In this situation, the co-drivers may more actively encode the instructions, whereas the drivers listen rather passively to this information. The question is whether people who control the instructions encode navigational information better (as they are more likely to connect the spatial information of the instructions with the environment) or worse (as reading the instructions rather deflects them from connecting the instructions with the environment), and whether the effect is the same for people who control movement and people who observe movement.

2.1.3 Goal and Instruction Specificity

Spatial learning during active navigation could also depend on people's expectations and cognitions. This is emphasized in the concept of goal specificity, which postulates that spatial learning depends on an intended goal (Taylor, Naylor, & Chechile, 1999). A route goal enhances performance on route perspective tasks; a survey goal enhances performance on survey tasks (see also Fields & Shelton, 2006; Foo et al., 2005; Rossano & Reardon, 1999; Shelton & McNamara, 2004). This concept contrasts the idea originally proposed by Siegel and White (1975) that spatial learning is a hierarchical process (starting with landmark via route to survey knowledge). Goal specificity possibly adds to the inconsistent findings in active navigation research: on the one hand, explicit instructions to memorize specific spatial information (e.g., landmark objects, Wilson, 1999) may have primed all participants on the specific spatial information, thus overshadowing effects of active versus passive navigation. On the other hand, participants who controlled their movement without any specific instruction may have automatically focused on the encountered route, enabling them to perform better in way-finding tasks.

The concept of goal specificity also implies that spatial knowledge is developed contingent on available information. For instance, individuals who studied maps of a virtual environment were superior in survey tasks, whereas individuals who navigated through the environment gave more accurate responses in route perspective tasks (Taylor et al., 1999). Moreover, spatial learning is influenced by subtle differences in the navigational instructions, such as the inclusion of either landmark or survey information into verbal descriptions (e.g., Reagan & Baldwin, 2006). If instructions emphasize, for example, landmark information, a benefit in landmark knowledge can be expected. This implies that in a yoked experimental design where the participant who controls movement receives specific instructions where to move based on landmark information (or survey information, respectively), an advantage in a corresponding spatial knowledge task over the participant who observes this movement may result either from the difference in movement control, or from the difference in instruction specificity. This possibility has not been accounted for in active navigation research yet.

2.1.4 The Role of Intention in Spatial Learning

Another explanation for the perceived route learning advantage of drivers compared to co-drivers could be different levels of attention, the reasoning being that drivers are forced to attend to their environment more closely. However, it can also be reasoned that co-drivers with the intention to remember a route may be equally attentive to the environment. This is even more likely in a laboratory setting, where most participants are likely to expect subsequent testing. Following this line of reasoning, Wilson and colleagues speculated on their finding of comparable spatial learning after active and passive navigation, that “all participants were specifically required to pay attention to the spatial properties of the environments. Given this directed attention, it may be that the spatial knowledge of passive participants was enhanced” (Wilson et al., 1997, p. 220). Thus, it is possible that the intention to learn about spatial properties compensates for differences between active and passive spatial learning. To our knowledge, there is as of yet no attempt to manipulate intention in spatial learning of a virtual environment, but a few studies in real environments have addressed the role of intention for spatial learning. An early study with children reported no differences between an intentional and an incidental learning condition (Herman et al., 1982), as did another study that was not primarily concerned with route learning (Dayan & Thomas, 1994). However, a recent study that manipulated intentional versus incidental learning in a route-learning task showed more promising findings (van Asselen, Fritschy, & Postma, 2006). The authors report no effects in landmark knowledge, but superior performance in survey knowledge tasks after intentional as compared to incidental learning. Their interpretation of this finding implies that landmark knowledge is processed automatically, but that the development of survey knowledge requires effortful processing. If learning intention benefits the processing of survey knowledge, this may override effects of movement control and result in comparable performance of self-contained and observed movement.

2.1.5 Aims of Chapter 2

To sum up, active navigation research has shown that greater involvement in navigating an environment may benefit spatial learning (i.e., by controlling movement, controlling decision, or related to additional information or learning intention). However, existing research on active navigation comprises a variety of methods and (consequently) findings, and different factors have been discussed as crucial to active navigation. The present research aims to disentangle movement control as a central factor from four factors that potentially affect active navigation. Thus, we manipulated movement control as a first independent variable in all experiments by testing participants in pairs, with one of them controlling movement and the other one observing this movement. Such a yoked design allows for the smallest possible differences in exposure between conditions.

As the second factor, we manipulated learning intention in Experiment 1, instruction specificity and instruction control in Experiment 2, and decision control in Experiment 3. These factors are not mandatory to self-contained movement because, for instance, an observer may direct another person where to move, thus being in control of decisions, but not in control of movement. An independent manipulation of a second factor may result in three possible patterns of findings. First, if self-contained movement provides genuine advantages for spatial learning as compared to observed movement, a second factor may affect spatial learning, but it will not change the advantage of self-contained over observed movement. Second, if self-contained movement appeared advantageous in previous studies because it has been confounded with the second factor, but the second factor is actually more important for developing spatial knowledge, disentangling the second factor from movement control will render differences between self-contained and observed movement oblivious. Third, if a second factor specifically affects self-contained, but not observed movement, the combination of self-contained movement and the second factor will be superior both to self-contained movement without the second factor as well as to observed movement in combination with the second factor.

In line with most recent studies in this field, we tested spatial knowledge for a specific route rather than for a virtual environment in general. This approach resembles real-life situations where navigation refers mostly to learning a route for a specific purpose rather than to a random exploration of an area. We used complex environments for similar reasons (see Wallet et al., 2008; Wilson et al., 1997, for further discussions of environment complexity).

In line with previous findings, we expected self-contained movement to enable better performance than observed movement in applied survey knowledge tasks such as way-finding, but comparable performance in more abstract survey knowledge tasks (e.g., pointing and sketch-mapping). Existing findings regarding landmark knowledge have been mixed, thus we attempted to explore further whether manipulations of movement control affect landmark knowledge.

2.2 Experiment 1

Experiment 1 manipulated learning intention in addition to movement control in order to test whether intentional learning might compensate for potential disadvantages of observed movement as compared to self-contained movement. In the intentional learning condition, the instruction explicitly stated that spatial knowledge would be tested later, and participants were required to answer a questionnaire on orientation strategies before the main experiment. In the incidental learning condition, participants were told that their ability to move in virtual environments would be evaluated, and they were given a corresponding questionnaire rather than a questionnaire on orientation strategies.

In order to exclude confounds of navigation instruction between conditions, navigation information was presented automatically and audible both to participants who controlled movement and participants who observed movement. We evaluated spatial memory with the most common spatial memory tests (i.e., a way-finding task, a pointing task, and a map-sketching task as indicators of survey knowledge, and a landmark recognition task as an indicator of landmark knowledge). Although we did not expect a specific effect in a landmark recognition task, we included landmarks that were more, or less, relevant for orientation. If there is no general difference between self-contained and observed movement in landmark knowledge, this may still be the case for landmarks that are more relevant for navigation. Previous studies on active navigation found no differences in map-sketching tasks, indicating that either active navigation does not benefit this task, or that this task is insensitive to manipulations of active navigation in complex virtual environments (e.g., due to task difficulty). Thus, instead of a map-sketching task, we included a simpler path-sketching task, where participants were required to outline the shape of the previously encountered route in an abstract scheme of the environment.

If learning intention was a crucial confound in previous studies, we should find an advantage of self-contained over observed movement in the incidental learning condition, but not in the intentional learning condition. Resembling findings from studies in real environments, learning intention should affect survey knowledge, but not landmark knowledge. Alternatively, effects of movement control on spatial learning could be independent of learning intention.

2.2.1 Method

2.2.1.1 Participants

Participants were 82 students (43 males), their age ranging between 19 and 33 years, *M* = 23.02, *SD* = 3.10. Given $\alpha = .05$ and $N = 82$, large between-subject effects ($d = .80$) could be detected with a statistical power of $1 - \beta = .95$ (Cohen, 1977).

2.2.1.2 Design

The independent variables were movement control (self-contained vs. observed movement) and learning intention (intentional vs. incidental learning), manipulated between subjects. Dependent variables were indicators of landmark knowledge (landmark recognition) and survey knowledge (tasks: pointing accuracy, path-sketching, and way-finding).

2.2.1.3 Materials

A grid of 6 × 7 fields was used as a basis for a virtual environment resembling an urban environment, constructed with the Quake III open source engine. The intended route resembled a cross and led through 22 fields including start and destination field. Four shortcuts at all arms of the cross as well as several dead ends were integrated into the environment. Each field contained one landmark (e.g., a car, a statue, or a stack of boxes). Among the encountered landmarks nine were passed straight (and were therefore of lower relevance for navigation), and eleven indicated a turn (and were of higher relevance).

Auditory route instructions were prerecorded and covered information about the route for the next one to three fields. The landmark of every field was mentioned, and general directions were given (e.g., “Turn right and pass the red bus, until you enter the car park!”). These instructions were integrated into the game engine and automatically triggered when a respective field was entered. Instructions were automatically repeated until participants left the trigger field in order to ensure that instructions were fully understood.

Mouse (head movement) and keys (W = forward, S = backward, A = moving left, D = moving right) controlled movement on G4 iBooks. Illustrations of movement control were visible through the whole experiment on a paper sheet. Batches on the lower left and right side of the computer screen indicated left and right to avoid direction confusions.

For the recognition task, screenshots of all 20 landmarks on the route as well as of 20landmarks in the environment (but not on the route) were color printed and presented after the study phase in randomized order. Participants were told to sort the 40 landmarks according to whether they had encountered them on the previous route or not.

For the pointing task, the destination field was displayed on the computer screen, which consisted of a room open to one direction only and a circle on the ground of this room that showed the degrees from 0 to 360 in steps of five. Participants were individually asked to look around by using the mouse in order to estimate the direction of three prominent features of the environment in degrees from their current position without leaving the destination room. These features were the start field and two other buildings shown as pictures, none of them visible from the destination room. Performance was evaluated by computing the mean absolute deviation in degrees from the original directions of the landmarks, with 0° indicating perfect pointing accuracy.

For the path-sketching task, we prepared a sheet of paper with an empty grid of 6x7 fields with an indication of the start field. In this task, participants were asked to draw the outline of the previously encountered route into the empty grid from the indicated start room. Performance in this task was evaluated by subtracting the number of wrong fields from the number of correct fields, and dividing the resulting score by the overall number of marked fields. This computation excludes effects of individual scaling tendencies (i.e., whether a participant marks very many or very few fields) and ranges between -1 and 1, the latter score indicating perfect performance. A score of 0 indicates that an equal number of correct and wrong fields were marked (given a route of 21 fields with exclusion of the indicated start field and a total of 42 fields, the ratio of possible correct and wrong fields is 21:20).

For the way-finding task, the environment was reset to the start field, and every participant was individually asked to take the fastest way to the destination room. Shortcuts were not mentioned explicitly. The computer automatically recorded a videotape of the performance in this task including exact time and chosen route for subsequent analysis.

We prepared two short questionnaires of five items each. One of them concerned experience with computer games (e.g., frequency of playing, experience with ego shooters), the other concerned orientation abilities and strategies (e.g., general sense of direction, focus on landmarks for orientation). All items were assessed with 5-point scales with higher values indicating more experience and better orientation, respectively.

2.2.1.4 Procedure

Participants were randomly assigned to the intentional or incidental learning condition. In the intentional learning condition, instructions stated that participants would be tested for their sense of orientation and their route memory. They received the orientation questionnaire before the study phase, and the computer games questionnaire at the very end of the experiment. In the incidental learning condition, instructions stated that participants would be tested for their ability to move smoothly in virtual environments. They received the computer game experience questionnaire before the study phase, and the orientation questionnaire at the very end of the experiment.

Participants of all experimental conditions were individually introduced to movement control and the automatic auditory instructions in a small practice environment for about one minute. The study phase was conducted in pairs. Both participants took place in front of one computer. Participants randomly assigned to the self-contained movement condition were asked to navigate according to the instructions. Participants in the observed movement condition were asked to take the time with a stopwatch as well as to monitor their partner not to take false turns. A steady time ($M = 128$ seconds, $SD = 19$) and low error rates ($M = 0.15$, $SD = 0.54$) indicated that navigating the environment worked well, with no differences between the intentional and the incidental learning conditions in two ANOVAs, both Fs < 1.34.

In the test phase, participants were seated in front of G4 iBooks in separate booths. After an unrelated distractor task of about two minutes length, pointing task, landmark recognition task, path sketching task, and way-finding task were applied in this order (with the reasoning that pointing would be the most difficult task, as well as that this order minimizes the chance to transfer knowledge gained during the test phase to a subsequent task). The experiment ended with a demographic questionnaire and the second questionnaire after about 30 minutes.

2.2.2 Results

2.2.2.1 Preliminary Analyses

For all statistical analyses throughout this research, the Type-I-error was set at $\alpha = .05$. As an indicator of the effect size, partial η^2 (η^2_p) is reported for statistically significant effects (Cohen, 1977).

We checked for potential confounds of sense of orientation and computer game experience, as indicated by the items “How good is your general sense of orientation?” ($M = 3.10$, $SD = 1.17$) and “How often do you play computer games?” ($M = 2.54$, $SD = 1.43$) with two separate 2 (movement control) × 2 (learning intention) ANOVAs. General sense of orientation and computer game experience did not differ between the experimental groups, all Fs < 1.32. A correlation analysis of these items with all dependent variables (landmark recognition hits and false alarms, pointing accuracy, path-sketching performance, and way-finding performance) revealed significant correlations of general sense of orientation with the number of recognition false alarms ($r = .24$) and with way-finding performance ($r = .28$), as well as significant correlations of computer game experience with the number of recognition hits ($r = .24$) and with way-finding performance ($r = .27$). To account for these correlations, we included sense of orientation and computer game experience as covariates in the respective analyses after linear relationships between covariates and dependent variables as well as homogeneity of regressions were tested and confirmed.

2.2.2.2 Landmark Knowledge

We assumed that landmarks that indicated a turn would be more relevant to navigation and thus easier to recognize than landmarks that were passed straight. Separate analyses of hit and false alarm percentage were necessary to test this assumption. A descriptive analysis of false alarms percentage indicated low averages and little variance between the experimental conditions (see Table 1). This was corroborated with a 2 (movement control) × 2 (learning intention) ANCOVA that indicated sense of orientation as a significant covariate, $F(1,75) = 4.63$, $\eta^2 = .06$, but showed no main or interaction effects on false alarm percentage, all Fs < 1.

For the analysis of hits percentage, we computed a 2 (movement control) × 2 (learning intention) × 2 (landmark relevance: indicating turns vs. passed straight) ANCOVA with repeated measurement on the last factor and computer game experience as a significant covariate, $F(1,78) = 5.49$, $\eta^2 = .07$. As can be seen in Table 1, hit percentage was generally higher for landmarks that indicated turns, and this advantage appeared more pronounced in the self-contained movement condition. The analysis corroborated the predicted main effect of landmark relevance, $F(1,78) = 7.75$, $\eta^2 = .09$. A main effect of movement control, $F(1,78) = 4.54$, $\eta^2 = .06$, indicated better landmark recognition after self-contained compared to observed movement. There was no main effect of intention, $F < 1$. Further, there was an interaction of movement control and landmark relevance, $F(1,78) = 4.28$, $\eta^2 = .05$. An analysis of simple main effects showed that self-contained movement enabled an additional recognition advantage of landmarks that indicated turns as compared to observed movement, $F(1,78) = 11.45$, $\eta^2 = .13$. There was also an interaction of intention and landmark relevance, $F(1,78) = 4.49$, $\eta^2 = .05$ (all other Fs < 1), indicating that intentional learning more strongly affected memory for landmarks passed straight than for those indicating turns. We refrain from further interpretation of this interaction because it is of little interest for active–navigation effects. Taken together, the data suggest better encoding of landmark knowledge after self-contained movement, but there was no effect of learning intention on landmark knowledge.

Table 1. Descriptive Means (and Standard Deviations) of All Dependent Variables in Experiment 1, Separately for All Experimental Conditions.

Task	**Condition**	Self-contained movement		Observed movement	
		Intentional learning	Incidental learning	Intentional learning	Incidental learning
LM False Alarms *M (SD)*:		6% (7)	9% (6)	8% (9)	9% (13)
LM Hits *M (SD)*	Indicating turns:	84% (13)	85% (9)	71% (23)	76% (12)
	Passed straight:	63% (18)	54% (21)	58% (24)	55% (16)
Pointing deviation *M (SD):*		73.47° (7.12)	71.80° (7.30)	75.06° (7.30)	87.09° (7.49)
Path-sketching *M (SD)*:		.18 (.25)	.22 (.24)	.27 (.24)	.21 (.30)
Way-finding *M (SD)*:		98secs (64)	101secs (30)	120secs (54)	119secs (41)

Note: Performance proportions of false alarms and hits are reported in the landmark recognition task. Pointing deviation indicates the mean absolute deviation in degrees from the original directions of the landmarks. Path-sketching performance ranges between -1 (only wrongly indicated fields) and 1 (only correctly indicated fields). Way-finding performance is presented in average time in seconds needed to move from start to destination.

2.2.2.3 Survey Knowledge

Pointing Accuracy & Path Sketching. As can be seen in Table 1, performance in both tasks was bad, with low scores in path sketching despite our effort to create a simpler task compared to conventional map sketching, and large deviations from the correct degree in the pointing task. Descriptively, pointing accuracy in the condition observed movement/incidental learning was worse than in the three other conditions. However, separate 2 (movement control) × 2 (learning intention) ANOVAs revealed no significant main or interaction effects for either dependent variable, all Fs < 1.36. Thus, movement control did not affect survey knowledge as assessed with these tasks, in line with previous research. Although it could be reasoned that this indicates comparable processing of survey information through self-contained and observed learning, we interpret this finding as an effect of task difficulty. In contrast to our expectations, no advantage of intentional over incidental learning in survey knowledge could be detected with the pointing task and the path-sketching task, either.

Way-finding time was log-transformed to achieve a normal distribution of the data. Self-contained movement resulted in better way finding than observation (presented in seconds in Table 1 for clarity). In contrast, performance appeared comparable after intentional and incidental learning. A 2 (movement control) × 2 (learning intention) ANCOVA with the significant covariates general sense of orientation, $F(1,74) = 4.86$, $\eta^2 = .06$, and computer game experience, $F(1,74) = 4.57$, $\eta^2 = .06$, confirmed these impressions by showing a main effect of movement control, $F(1,74) = 4.95$, $\eta^2 = .06$, but no main effect of intention and no interaction effect, both Fs < 1. Thus, in line with previous studies, self-contained movement benefitted way-finding performance.

It can be argued that this effect resulted from increased movement practice in the study phase, despite our efforts to avoid such an effect with an initial practice trial. We addressed this concern by analyzing the way-finding recordings for the number of fields that were encountered during the way-finding task, as well as for the number of used shortcuts. If the disadvantage of observed movement results from a lack of movement practice rather than from the inability to identify an efficient route, there should be no advantages of self-contained movement for these variables. Two separate 2 (movement control) × 2 (learning intention) ANOVAs showed that participants in the self-contained movement condition used more shortcuts than participants who observed movement ($M = 1.12$, $SD = 0.12$, and $M = 0.61$, $SD = 0.12$, respectively), $F(1,79) = 8.60$, $\eta^2 = .10$. This contributed to an overall smaller number of encountered fields after self-contained movement compared to observed movement (*M* = 18.84, *SD* = 1.11, and *M* = 22.03, *SD* = 1.14, respectively), *F*(1,78) = 4.02, η^2 = .05. Thus, self-contained movement led to better way-finding performance because a more efficient route was identified, not due to more movement practice.

2.2.3 Discussion

Experiment 1 tested the effects of self-contained versus observed movement and intentional versus incidental learning on different levels of spatial knowledge. Regarding the effects of movement control, our findings are in line with previous research: Self-contained movement enabled better way-finding performance than observed movement, but comparable path-sketching performance and pointing accuracy. Contrasting some, but not all previous studies, we found better landmark recognition after self-contained movement, which was most pronounced for more relevant landmarks. Thus, self-contained movement provides advantages over observed movement in tasks that require more applied landmark and route knowledge, rather than in classic survey knowledge tasks. We reason that despite modern 3D graphics and a general comparability of virtual and real environments, complex virtual environments may be too alien and too abstract to most people to enable the rapid development of a mental map as assessed by classic survey knowledge tasks. Thus, these tasks appear to suffer from a floor effect.

We manipulated learning intention as the second independent factor and expected effects in survey knowledge, but not in landmark knowledge. However, intentional learning showed few if any effects over incidental learning. We cannot completely rule out the possibility that our manipulation of intention was insufficient, as true incidental learning in an experimental setting is difficult to accomplish (Dayan & Thomas, 1994). However, we found no hint that intentional learning benefits survey knowledge in complex virtual environments or that there may have been a confound of learning intention and movement control in previous studies.

In sum, these findings imply that observed movement is rather inferior to self-contained movement for achieving spatial knowledge of a virtual environment, and that the disadvantage of observed movement cannot be countered by intentional learning. However, participants who observed movement were mostly uninvolved in navigating the environment: they were neither able to influence the course taken, nor were they required to pay close attention to the verbal instructions. Previous research suggests that a greater involvement in the navigation process and the availability of more or less specific spatial information is crucial to spatial learning. Thus, if participants in the observed movement condition are more involved in the navigation process, they may develop comparable spatial knowledge to participants in the self-contained movement condition. Additionally, the navigational information in Experiment 1 presented landmark information, thus inducing a landmark-based rather than a survey-based encoding strategy (Taylor et al., 1999). This may have added to the null findings in the survey knowledge tasks. Both issues are addressed in Experiment 2.

2.3 Experiment 2

Experiment 2 was designed to manipulate instruction control and instruction specificity in addition to movement control. It seem plausible that navigational instructions that need to be more actively studied are more likely to be linked to spatial properties of the environment, and may thus benefit spatial learning. Thus, navigational instructions were not presented automatically to both participants as in Experiment 1, but one participant was assigned to the navigator role and instructed the other, listening participant where to move using verbal information. Additionally, we varied instruction specificity: participants received instructions that either contained landmark information only (comparable to Experiment 1), or additional survey information (see Reagan & Baldwin, 2006; Zimmer, 2004, for similar approaches). This manipulation of instruction control resulted in two possible pairings. In one pairing, one participant controlled movement and received instructions about the route (the landmark or the survey version, respectively), with the other participant as a completely passive, listening observer. In the other pairing, the participant who observed movement received the instructions about the route (the landmark or the survey version, respectively) and directed the participant who controlled movement.

Based on the results of Experiment 1, we concentrated on landmarks relevant for navigation. We refrained from further using a pointing task due to the null finding in this task. We were interested in knowing whether an easier survey knowledge task would be more sensitive to our experimental manipulations. Therefore, we changed the path-sketching task to a tour-integration task, where participants were required to draw the encountered tour into an abstracted map of the environment. Similar approaches have been used in real environments, where this task has been found to be a valid measure of survey knowledge (van Asselen et al., 2006).

If instruction control is a factor crucial to spatial learning, we can expect better performance when instructing someone else compared to only listening to someone's instructions. On the one hand, instruction control might enable to compensate disadvantages in spatial learning, if it assures a greater involvement in navigation of participants who observe movement. On the other hand, instruction control might further increase the advantage of self-contained movement, if it focuses participants controlling their movement on the provided spatial information.

These effects may be further modified by instruction specificity. We expect those navigation instructions that consist of landmark information (i.e., about the upcoming landmarks and the next turn) to affect landmark knowledge tasks, but to a smaller degree survey knowledge tasks. Conversely, we expect that navigation instructions that consist of additional survey information (e.g., about the shape of a room that has to be crossed) affect survey knowledge tasks, but to a smaller degree landmark knowledge tasks. If instruction specificity is separated from movement control, disadvantages of observed movement in contrast to self-contained movement may not be observed anymore in spatial knowledge tasks that match the spatial information in the instructions. Alternatively, it is possible that instruction specificity increases an existing advantage of self-contained movement.

2.3.1 Method

2.3.1.1 Participants

Participants were 90 students (10 males). Age ranged between 18 and 33 years, M = 21.01 years, SD = 2.85. Given $\alpha = .05$ and $N = 90$, large between-subjects interaction effects ($d = .80$) could be detected with a statistical power of $1 - \beta = .93$ (Cohen, 1977).

2.3.1.2 Design

The independent variables were movement control (self-contained vs. observed movement), instruction control (instructing vs. listening), and instruction specificity (survey information vs. landmark information), manipulated between subjects in a 2 × 2 × 2 design. Dependent variables were related to landmark knowledge (landmark recognition) and survey knowledge (tour-integration and way-finding).

2.3.1.3 Materials

The material and apparatus are identical to Experiment 1 if not mentioned otherwise. We created another virtual environment on the basis of a 10 × 10 fields grid. Eight main rooms of varying size and shape connected start and destination. Each room was also connected to a third dead-end room, resulting in a total of eighteen rooms. When constructing the environment, care was taken that dead-ends mostly ended adjacent to other rooms (but without a connection between them, see Figure 1).

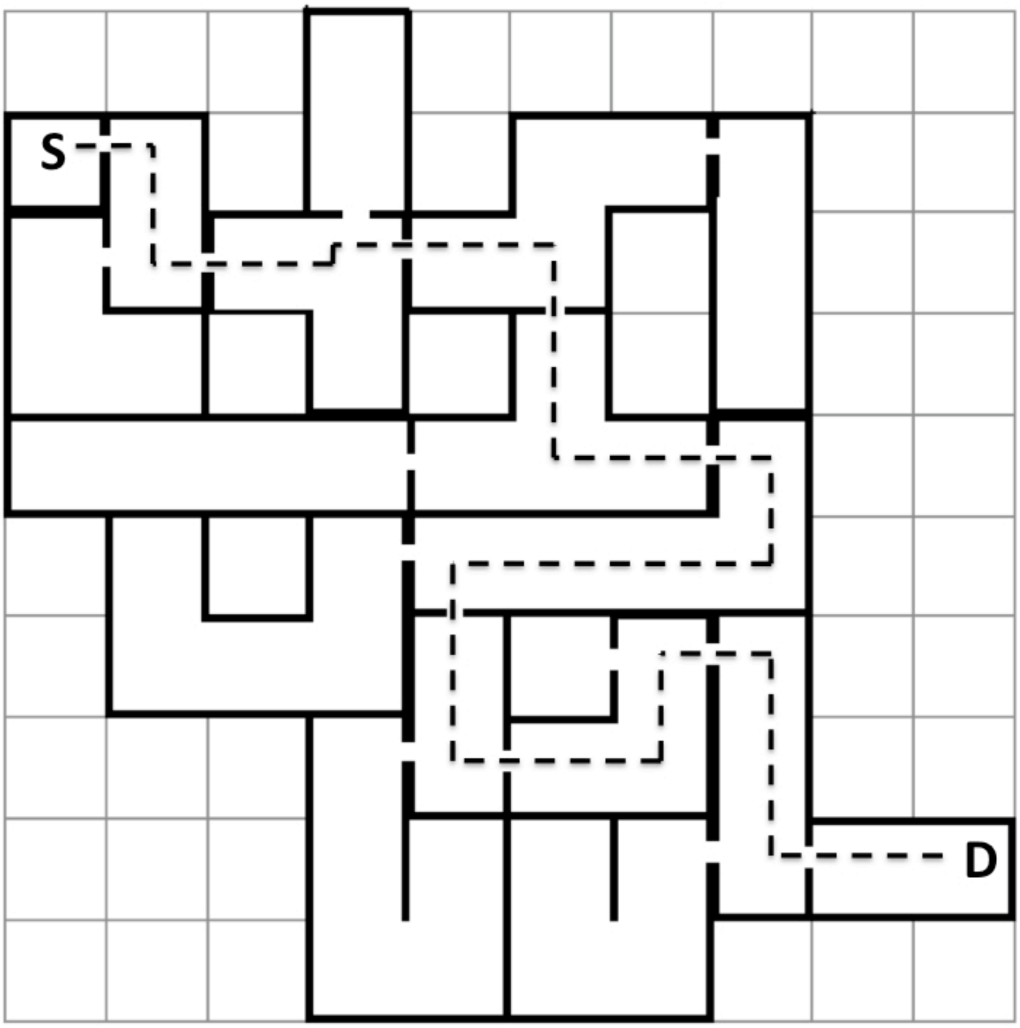

Figure 1. Map of the environment used in Experiment 2. Black lines represent walls. All connections between rooms are indicated. The dotted line represents the intended route from start room (S) to destination (D).

One landmark was positioned in every main room, resulting in a total of eight landmarks. Arrow keys controlled movement (Up = Forward, Down = Backward, Left = Turning left, Right = Turning right). Navigation instructions were presented in written form in postcard-size booklets. In the landmark information condition, each page contained one sentence that named the next landmark and the correct exit to the next room (e.g. "Turn left at the wardrobe!"). In the survey information condition, every room was described with three sentences, mentioning the landmark and its position in the room, as well as the shape of the room and the correct exit (e.g., “The next room is L-shaped. It contains a wardrobe at its end. Use the left door!”).

For the recognition task, screenshots of all eight landmarks as well as screenshots of eight distractor landmarks were prepared. Participants were presented with four original and four distractor landmarks in quasi-randomized and counterbalanced order and asked to indicate whether they had seen these landmarks, or not. For the tour-integration task, a schematic overview of the environment was prepared that showed outlines of all main and dead-end rooms as well as start and destination, but neither landmarks nor passages between the rooms. Participants were asked draw a line connecting start and destination (see Figure 2). Computation of performance scores was identical to the path-sketching task in Experiment 1.

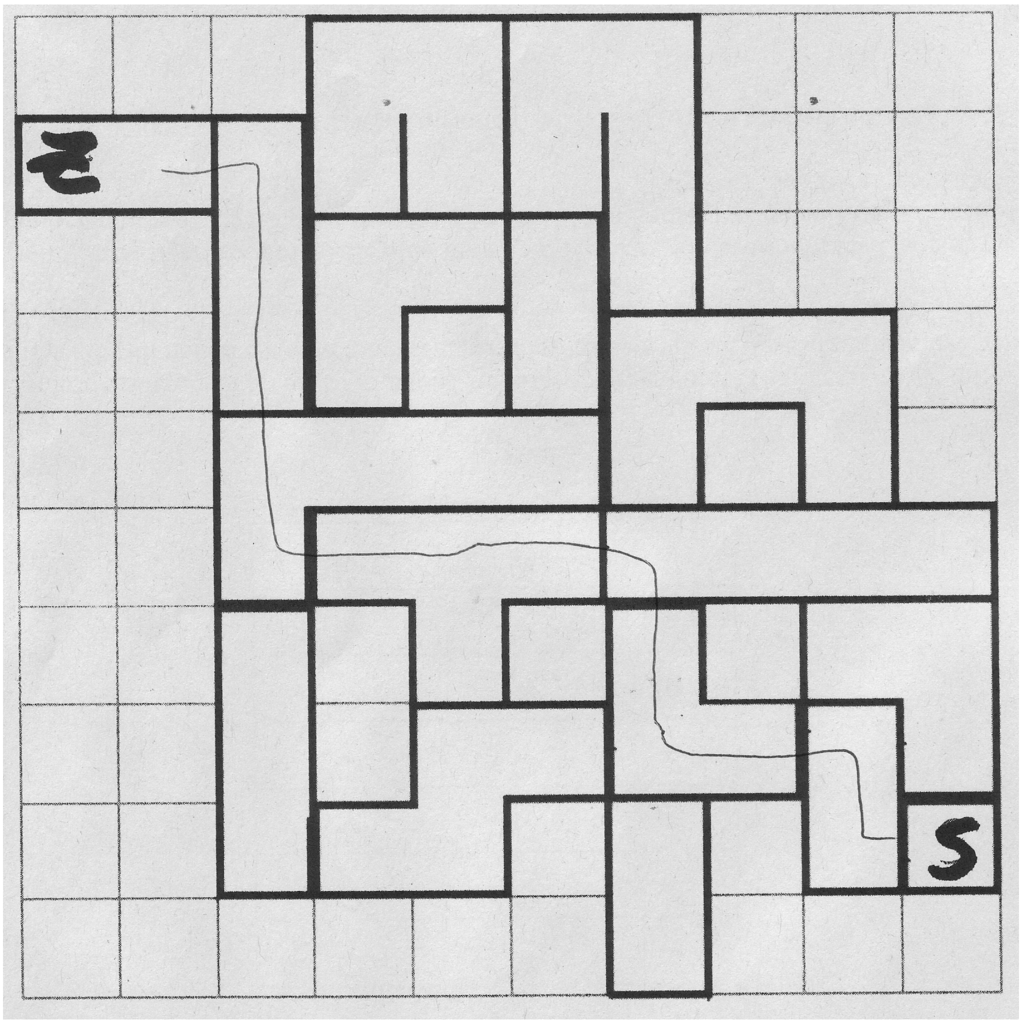

Figure 2. Example of tour-integration performance taken from the data sample of Experiment 2. Note that connections between rooms are not indicated in this version of the map as compared to Figure 1. The thin pen-line displays the route indicated by the participant. The Z responds to “Ziel” (German for destination).

2.3.1.4 Procedure

The procedure was identical to Experiment 1 if not mentioned otherwise. Participants were again tested in pairs and randomly assigned to the experimental conditions. Instruction control was manipulated by assigning one participant the navigator role. This participant received the navigation instructions and mentioned all instruction information aloud to the listening partner. The navigation instructions consisted either of landmark information only, or additional survey information. This resulted in two possible pairings. In one pairing, the participant who controlled movement but did not control instruction information had to listen to all directions given by the observing partner, who directed the partner through the environment according to the instructions received. In the other pairing, one participant controlled both movement and instructions and was told to mention all instruction information aloud to the observing and listening partner, in order to keep auditory information comparable across all conditions. In both pairings, participants navigated through the environment until they arrived at the destination.

In the test phase, participants were seated individually and worked on an unrelated distractor task for about two minutes, followed by the tour-integration task and the landmark recognition task. In the final way-finding task, the environment was reset to the start room, and participants were instructed to find the destination as fast as possible. Demographic data and computer game experience were assessed before debriefing. The experiment took about 30 minutes.

2.3.2 Results

2.3.2.1 Preliminary Analyses

We checked for potential confounds of computer game experience (M = 1.19, SD = 0.92) with a 2 (movement control) × 2 (instruction control) × 2 (instruction specificity) ANOVA. Computer game experience did not differ between the experimental groups, all Fs < 1. A correlation analysis of computer game experience with all dependent variables (landmark recognition hits and false alarms, tour-integration performance, and way-finding performance) revealed a significant correlation of computer game experience with way-finding performance (r = .32). We included computer game experience as a covariate in the respective analysis after confirming that all assumptions held, as in Experiment 1.

2.3.2.2 Landmark Knowledge

To be consistent with Experiment 1, false alarms and hits were again analyzed separately. As can be derived from Table 2, there were fewer false alarms and more hits after self-contained than after observed movement. For false alarm percentage, a 2 (movement control) × 2 (instruction control) × 2 (instruction specificity) ANOVA revealed a main effect of movement control, $F(1,82) = 4.30$, $\eta^2 = .05$, all other Fs < 3.46. The analysis of hit percentage also indicated a main effect of movement control, $F(1,82) = 7.27$, $\eta^2 = .08$. Contrasting our expectation, we found neither a main effect of instruction specificity nor an interaction effect. There was also no effect of instruction control (all Fs < 2.72). Thus, instructing someone where to move did neither enable participants in the observed movement condition to develop landmark knowledge comparable to participants in the self-contained movement condition, nor did it provide an additional advantage to participants in the self-contained movement condition.

Table 2. Descriptive Means (and Standard Deviations) of All Dependent Variables in Experiment 2, Separately for All Experimental Conditions.

Instruction specificity	Survey information				Landmark information			
Movement Control	Self-contained		Observed		Self-contained		Observed	
Task **Instruction control**	Instructing	Listening	Instructing	Listening	Instructing	Listening	Instructing	Listening
LM False Alarms *M (SD)*:	13% (21)	13% (17)	13% (19)	23% (18)	10% (13)	2% (7)	25% (20)	13% (32)
LM Hits *M (SD)*:	88% (19)	91% (13)	81% (22)	70% (20)	80% (20)	87% (13)	78% (22)	73% (22)
Tour-integration *M (SD)*:	.61 (.29)	.37 (.26)	.22 (.15)	.51 (.30)	.35 (.31)	.59 (.30)	.39 (.26)	.37 (.24)
Way-finding *M (SD):*	87secs (62)	147secs (84)	133secs (49)	109secs (76)	93secs (28)	114secs (72)	133secs (73)	116secs (34)

Note: Performance proportions of false alarms and hits are reported in the landmark recognition task. Tour-integration performance ranges between -1 (only wrongly indicated rooms) and 1 (only correctly indicated rooms). Way-finding performance is presented in average time in seconds needed to move from start to destination.

2.3.2.3 Survey Knowledge

Tour-integration appears to be more sensible to detect differences in survey knowledge about virtual environments than classic survey knowledge tasks: Whereas the performance in all experimental conditions that received instructions with landmarks only was quite consistent, performance varied more after receiving instructions with additional survey information (see Table 2). More specifically, performance was best for participants in the self-contained movement condition who instructed their partners, but worst for participant in the observed movement condition who instructed their partners. In a 2 (movement control) × 2 (instruction control) × 2 (instruction specificity) ANOVA, a main effect of movement control missed significance, $F(1,82) = 3.18$, $\eta^2 = .04$, $p = .08$, and there were no other main effects or first-order interactions (all Fs < 1.35). However, the second-order interaction of all factors was significant, $F(1,82) = 11.09$, $\eta^2 = .12$. To analyze this interaction further, we computed two 2 (movement control) × 2 (instruction control) ANOVAs, separately for each level of instruction specificity. There were no significant effects in the landmark information ANOVA (all Fs < 2.27). In the survey information ANOVA, movement control and instruction control interacted significantly, $F(1,40) = 10.62$, $\eta^2 = .21$ (other Fs < 2.25). An analysis of simple main effects revealed that in the self-contained movement condition, tour-integration was superior after instructing survey information than listening, $F(1,40) = 5.32$, $\eta^2 = .12$, but in the observed movement condition, listening to survey information led to better tour-integration than instructing, $F(1,40) = 5.37$, $\eta^2 = .12$. Additionally, when instructing survey information, tour-integration after self-contained movement exceeded that after observed movement, $F(1,40) = 11.29$, $\eta^2 = .22$, but there was no significant difference between the movement control conditions for listening to survey instructions, $F < 1.55$. Thus, in line with our instruction specificity hypothesis, additional survey information affected survey knowledge. However, whether survey information had a beneficial effect or not depended on how it was received: when movement was observed, listening to the instructions resulted in better tour-integration performance. When movement was self-contained, instructing navigational information resulted in better tour-integration performance.

Way-finding time was log-transformed prior to analysis to achieve a normal distribution. Self-contained movement seemed to enable generally better performance than observed movement (with the exception of participants who controlled movement and listened to survey information, see Table 2). A 2 (movement control) × 2 (instruction control) × 2 (instruction specificity) ANCOVA with computer game experience as a significant covariate, $F(1,80) = 12.31$, $\eta^2 = .13$, revealed a main effect of movement control, $F(1,80) = 4.14$, $\eta^2 = .05$, that was qualified by an interaction of movement control and instruction control, $F(1,80) = 7.92$, $\eta^2 = .09$ (all other Fs < 3.81). For clarification, this interaction is displayed in Figure 3. An analysis of simple main effects indicated significantly better performance of self-contained movement and instructing compared to observed movement and instructing, *F*(1,80) = 11.49, η^2 = .13, as well as compared to self-contained movement and listening, *F*(1,80) = 7.65, η^2 = .09 (all other *F*s < 1.81). Thus, way-finding performance was less dependent on instruction specificity but more on how instructions were received: participants in the self-contained movement condition were only able to apply navigational information in the way-finding task when they had read it themselves, but not when they had just listened to it, and vice versa for participants in the observed movement condition.

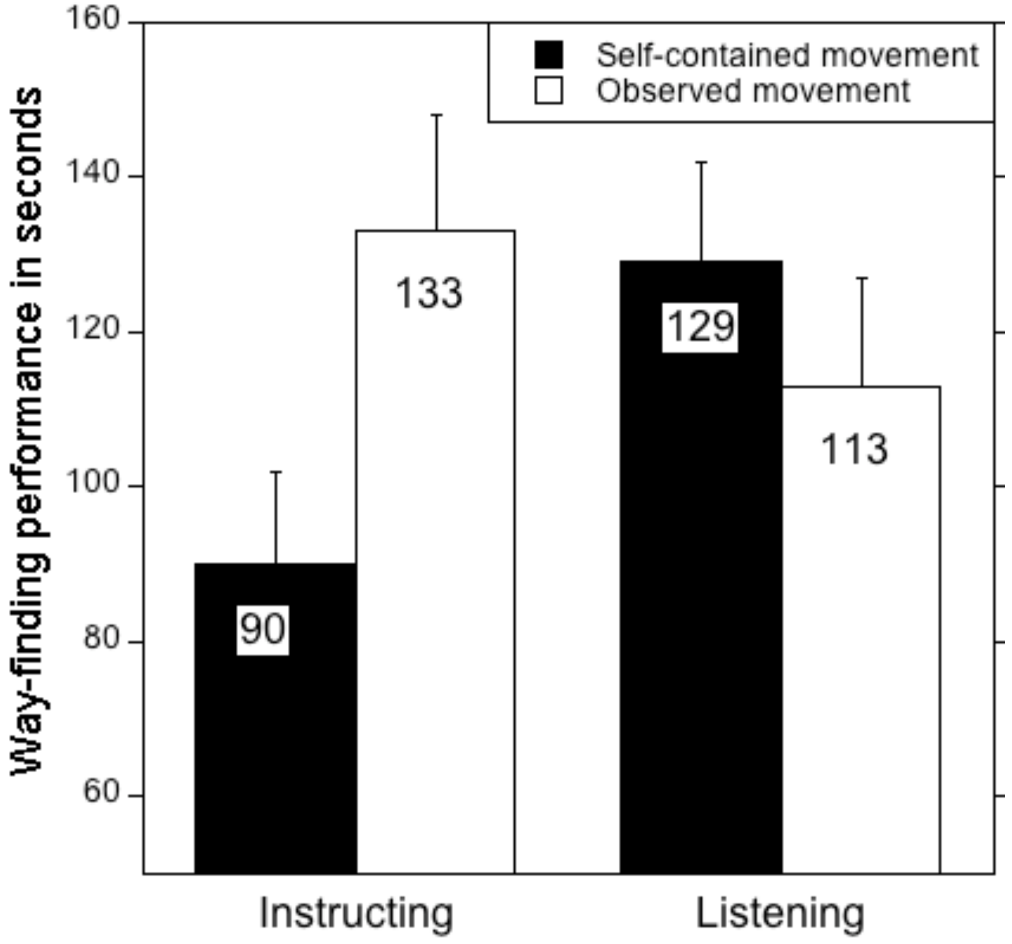

Figure 3. Descriptive means of the way-finding task in Experiment 2, separately for movement control and instruction control. Error bars represent standard errors.

2.3.3 Discussion

Experiment 2 manipulated instruction control and instruction specificity in addition to movement control by providing participants with verbal landmark information or verbal survey information, which participants either read or listened to. We hypothesized that manipulations of instruction control and instruction specificity could either annihilate differences of movement control, or result in additional benefits of self-contained movement.

The way-finding task provided evidence for the latter assumption: The combination of self-contained movement with instruction control enabled superior performance in this task. The data pattern of the tour-integration task resembles that in the way-finding task, but only when instructions included additional survey information. Again, the combination of self-contained movement with instruction control enabled the best performance. We speculate that the combination of these factors displays an example of interactive context encoding (Baddeley, 1982), where the presented information becomes part of the specific action of maneuvering and is consequently better encoded. By contrast, this implies that without instruction control, spatial learning through observed movement can equal that of self-contained movement.

As in Experiment 1, landmark knowledge was better after self-contained movement. Moreover, landmark knowledge after self-contained movement appeared robust across all levels of instruction control and instruction specificity. It should be noted that all landmarks were also named in the survey information instructions. This may have masked negative effects of survey information on landmark knowledge.

Taken together, instruction control seems to be crucial for superior processing of survey knowledge with self-contained as compared to observed movement: People who controlled their movement were only superior when they controlled the instructions. This was more pronounced when the navigational information consisted of additional survey information. Without instruction control and additional survey information, spatial learning of self-contained and observed movement was rather comparable. However, the present manipulations did not require decision-making, as participants followed a pre-selected route. Several studies (Carassa et al., 2002; Farrell et al., 2003; Wilson et al., 1997) emphasize the importance of decision-making, suggesting that deciding about where to move is more important than the actual movement. Thus, whereas participants in the self-contained movement condition integrated the specific instructions into their processing of spatial information, giving the specific instructions did not require active elaboration by participants in the observed movement condition. This may have resulted in their inferior spatial learning. If participants in the observed movement condition are required to elaborate the navigation instructions more actively, they may show comparable spatial learning. Thus, decision-making was manipulated in Experiment 3.

2.4 Experiment 3

Experiment 3 was designed to manipulate decision-making in navigation in addition to movement control. However, inducing decision-making with verbal descriptions of a route was hard to conceive. Thus, we presented fragmented maps as navigation instructions (see Münzer et al., 2006; Zimmer, 2004, for similar approaches). Navigation with maps can be expected to create a bias towards a survey representation (Taylor et al., 1999), and may result in a very different mental representation of the environment than having seen no map (Willis et al., 2009). For example, participants who navigate with maps may be deflected from encoding landmark information. Thus, it was necessary to implement a control condition that included maps for navigation to guarantee a comparable mental representation of the environment, but that did not require decision-making about the correct route. We therefore adapted Farrell and colleagues' (2003) approach of self-contained movement with or without additional indications of the optimal route in the environment in our yoked participant setting. Participants in the active navigation condition received fragmented maps that required decision-making, consisting of start and destination only. A careful design of the fragments required these participants to identify and decide about the optimal route between start and destination, but guided them unobtrusively on an intended course. Participants in the passive navigation condition received the same map segments including indications of the optimal route, consequently requiring less decision-making. Participants in a no-navigation condition did not receive map instructions at all.

If self-contained movement requires decision control for a good encoding of spatial information, we can expect the best performance for the combination of self-contained movement and decision control in tour-integration. However, if decision control is more relevant than movement control as suggested by previous research, decision control, but not movement control, should determine tour-integration performance. A way-finding advantage of self-contained over observed movement can be expected, because participants in the self-contained movement condition appeared to be generally advantaged in the previous experiments. However, if the active processing of maps enables participants in the observed movement condition to apply this configurational information in the way-finding task, this may result in performance comparable to that of participants in the self-contained movement condition. In line with the previous experiments, we expect better landmark knowledge after self-contained movement compared to observed movement.

2.4.1 Method

2.4.1.1 Participants & Design

Participants were 103 students (21 males). Age ranged between 19 and 41 years, M = 21.25, SD = 2.66. Given $\alpha = .05$ and $N = 103$, large between-subject interaction effects (d = .80) could be detected with a statistical power of $1 - \beta = .96$ (Cohen, 1977). Independent variables were movement control (self-contained movement vs. observed movement) and decision control (active vs. passive vs. no navigation), manipulated between subjects. Dependent variables were identical to Experiment 2.

2.4.1.2 Materials & Procedure

Materials and procedure correspond to Experiment 2 if not mentioned otherwise. Another virtual environment was created. The intended route consisted of three segments with 24 rooms total. Several dead ends were included, resulting in an environment of 38 rooms. The intended route contained sixteen evenly distributed landmarks (e.g., a couch or a bookshelf).

Navigation information was presented with three map segments of about letter size showing the outlines of the environment and all connections between the rooms, but no landmarks. The map segments were designed to include several dead-ends. In line with the starts and destinations on each map segment, red flags indicated starts and destinations in the virtual environment. The navigating participants received one map segment at a time. In the active navigation condition, start and destination were marked with red dots (see left panel of Figure 4). Participants were asked to identify and use the shortest possible route. Thus, they were required to choose the optimal route and to actively elaborate the map segments, but were unobtrusively guided on the course we had intended. Participants in the passive navigation condition received identical map segments, but the shortest way was marked with a red line (see right panel of Figure 4). Thus, participants in the passive navigation condition clearly received *more* information than those in the active navigation condition, which should lead to *less* decision-making about the optimal route and thus less spatial learning. Participants in the no-navigation condition received no map segments at all. The respective map segment was visible to the navigating participant for the whole time spent in the respective part of the environment, but not to the passive partner. After arriving at the destination of one map segment, the experimenter handed the navigating participant the next map segment.

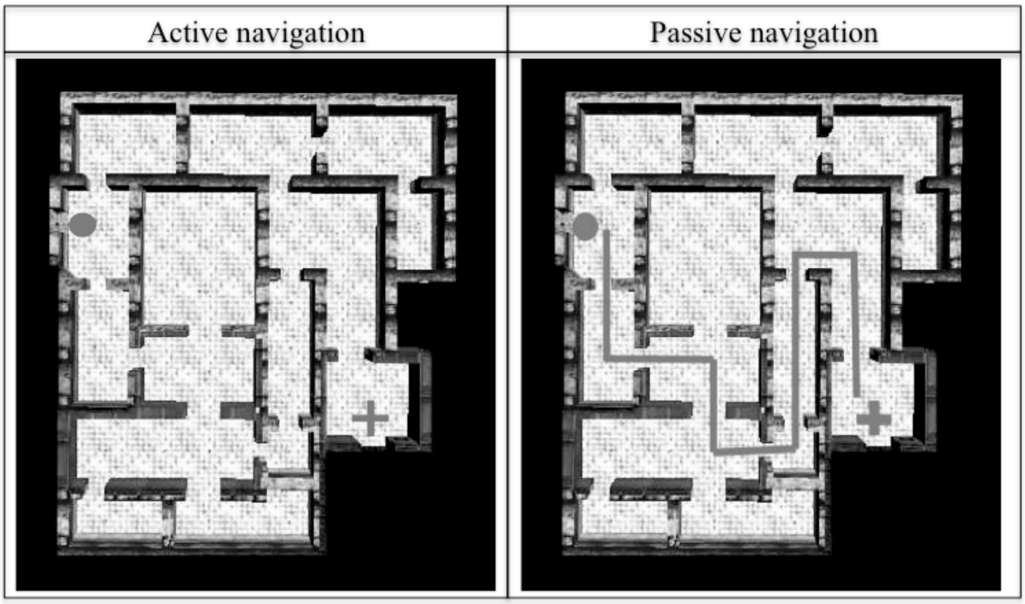

Figure 4. The second map segment as it was presented to the participants in Experiment 3. In the active navigation condition, only start and destination are indicated. In the passive navigation condition, a line indicates the optimal course between start and destination.

To test landmark knowledge in a recognition task, screenshots of 16 landmarks as well as 16 distractor landmarks were used. Each participant was shown eight original and eight distractor landmarks in quasi-randomized and counterbalanced order. For the tour-integration task, schematic overviews of all map segments were prepared as in Experiment 2 (i.e., passages between rooms were not indicated). Participants received one schematic overview at a time and were instructed to draw the encountered route. Way-finding task, distractor task, task order and questionnaire including demographic data were identical to Experiment 2. The whole experiment lasted about 30 minutes.

2.4.2 Results

2.4.2.1 Preliminary Analyses

Computer game experience (*M* = 2.15, *SD* = 0.97) did not differ between the experimental groups, as a 2 (movement control) × 3 (decision control) ANOVA showed (all *F*s < 1). A correlation analysis of computer game experience with all dependent variables (landmark recognition hits and false alarms, tour-integration performance, and way-finding performance) revealed a significant correlation of computer game experience with way-finding performance (*r* = .26). We included computer game experience as a covariate in the respective analysis after confirming that all assumptions held.

2.4.2.2 Landmark Knowledge

An analysis of false alarm percentage yielded no effects, all *F*s < 1. The descriptive data in Table 3 indicated better hit recognition performance after self-contained than observed movement. Additionally, performance in the no-navigation condition appeared superior to the other navigation conditions. The analysis of hit percentage with a 2 (movement control) × 3 (decision control) ANOVA corroborated these impressions with a main effect of movement control, $F(1,96) = 4.30$, $\eta^2 = .04$, and an effect of decision control, $F(2,96) = 4.95$, $\eta^2 = .09$. There was no interaction effect, $F < 1$. Thus, self-contained movement enabled better landmark knowledge as in the previous experiment, and navigating with maps deflected participants from encoding landmark knowledge as hypothesized.

Table 3. Descriptive Means (and Standard Deviations) of All Dependent Variables in Experiment 3, Separately for All Experimental Conditions.

Condition	Self-contained movement			Observed movement		
Task	Active navigation	Passive navigation	No navigation	Active navigation	Passive navigation	No navigation
LM False Alarms *M (SD)*:	42% (14)	41% (16)	44% (17)	37% (19)	41% (17)	40% (15)
LM Hits *M (SD)*:	45% (16)	53% (20)	61% (20)	42% (18)	41% (13)	53% (18)
Tour-integration *M (SD)*:	.48 (.20)	.48 (.19)	.21 (.20)	.70 (.14)	.51 (.14)	.23 (.10)
Way-finding *M (SD):*	165secs (57)	149secs (56)	157secs (56)	193secs (64)	224secs (66)	169secs (70)

Notes: Performance proportions of false alarms and hits are reported in the landmark recognition task. Tour-integration performance ranges between -1 (only wrongly indicated rooms) and 1 (only correctly indicated rooms). Way-finding performance is presented in average time in seconds needed to move from start to destination.

2.4.2.3 Survey Knowledge

Tour-integration performance was strongly affected by decision control (see Table 3), with the strongest performance after active navigation, and distinctively weak performance in the no-navigation condition. The data also imply an advantage of observed over self-contained movement in the active navigation condition. These impressions were corroborated in a 2 (movement control) × 3 (decision control) ANOVA. Confirming our assumptions, we found a strong effect of decision control on tour-integration performance, $F(2,96) = 42.88$, $\eta^2 = .47$, and a main effect of movement control, with better performance after observed as compared to self-contained movement, *F*(1,96) = 6.59, η^2 = .06. These effects were qualified by an interaction, *F*(2,96) = 3.97, η^2 = .08. Analyses of simple main effects corroborated that active navigation benefitted participants in the observed movement condition more than participants in the self-contained movement condition, *F*(1,96) = 16.44, η^2 = .15. A second simple main effect indicated that active navigation exceeded passive navigation and no-navigation in the observed movement condition *F*(2,96) = 36.25, η^2 = .43, but not in the self-contained movement condition, $F < 1$. These findings of the tour-integration task are in line with previous research: decision control was more important to active navigation than movement control.

Way-finding performance was about comparable for all self-contained movement conditions. In comparison, performance after observed movement appeared (as compared to self-contained movement) distinctively worse in the passive navigation condition and somewhat decelerated in the active navigation condition, but not in the no-navigation condition (see Table 3). Way-finding time was log-transformed and included in a 2 (movement control) × 3 (decision control) ANCOVA with computer game experience as a significant covariate, *F*(1,94) = 12.82, η^2 = .12. There was a main effect of movement control, *F*(1,94) = 11.87, η^2 = .11, no effect of decision control, $F < 2.10$, but an interaction of both factors, *F*(2,94) = 3.02, η^2 = .06. Analyses of simple main effects revealed a significant advantage of self-contained over observed movement for passive navigation, *F*(2,94) = 14.67, η^2 = .14, that was reduced for active navigation, $F = 3.05$, $p = .08$. Thus, active navigation enabled participants who observed movement to compensate for disadvantages in way-finding.

2.4.3 Discussion

Experiment 3 included an element of choice in the navigation instructions, thus contrasting movement control against decision control. Consistent with the previous experiments, self-contained movement enabled better landmark recognition performance than observed movement. Additionally, the no-navigation condition showed better landmark knowledge than the active and the passive navigation conditions, respectively.

As expected, tour-integration performance was strongly affected by map-based instructions. Obviously, passive navigation without maps resulted in noticeably declined performance compared to the other navigation conditions. One could argue that the finding of better representation of maps after more active encoding of the maps is not particularly impressive, because an exposure to the environment was actually not necessary to perform well in the tour-integration task. However, although self-contained and observed movement did not differ in the passive and in the no-navigation condition, performance in the active navigation condition was significantly better after observed movement than after self-contained movement. Apparently, the combined cognitive demands of self-contained movement and active navigation with the map segments limited encoding of the map segments. This implies that self-contained movement can inhibit spatial learning in certain cases.

More importantly, decision control affected way-finding performance: Only in the passive navigation condition did observed movement result in significantly slower way-finding than self-contained movement. The difference in the active navigation condition was not significant. Thus, active navigation supported the way-finding ability of participants who observed movement. Performance in the no-navigation condition was surprisingly good for both movement control conditions. In our interpretation, participants in the no-navigation condition used a landmark-based approach in the way-finding task (as indicated by their superior landmark recognition) rather than a map-based approach as the other navigation conditions. This strategy was sufficient for identifying an efficient route also after observed movement.

Taken together, these findings imply that active decision control with map-based instruction is more important to spatial learning than movement control as indicated by comparable (way-finding task) or even better (tour-integration task) spatial learning after observed movement compared to self-contained movement. However, navigation with maps also deflected from the encoding of landmark knowledge as predicted by findings on goal specificity (e.g., Taylor et al., 1999) and may display a disadvantaging factor for way-finding, if way-finding on a landmark-based strategy is possible.

2.5 Discussion of Series 1

The aim of the present series of experiments was disentangling the effects of movement control on spatial learning from other factors that have been considered as relevant in active navigation research; namely learning intention (Experiment 1), instruction control and instruction specificity (Experiment 2), as well as decision control (Experiment 3). In all experiments, participants studied a specific route in a yoked design with one person controlling movement (self-contained movement condition) and another person observing this movement (observed movement condition). In Experiments 2-3, either of them was responsible for navigation with verbal route descriptions (Experiment 2) or with fragmented maps (Experiment 3). Our aim was to clarify whether self-contained movement leads to a genuine advantage in spatial learning of virtual environments, and whether such an advantage is further supported or inhibited by other factors. In sum, the results suggest that self-contained movement provides a genuine advantage for the encoding of landmark knowledge as compared to observed movement. This is not true for the development of survey knowledge, where an advantage of self-contained movement depends on additional factors as discussed in detail below.

We found consistently superior landmark knowledge after self-contained as compared to observed movement in congruence with some previous studies (e.g., Hahm et al., 2007), whereas most studies on landmark knowledge in virtual environments did not report such an effect (Brooks et al., 1999; Wallet et al., 2008; Wilson, 1999). One possible explanation for this difference is that in contrast to most of the mentioned studies, the navigational instructions in Experiments 1-2 named all landmarks explicitly, provoking interactive context integration (Baddeley, 1982): Through the indication and perception of a landmark at a specific place in the environment in combination with self-contained movement, the landmark-object may have become part of the specific action of maneuvering and consequently be better recognized. However, the landmark knowledge advantage also appeared in Experiment 3, where the landmarks were not explicitly mentioned. We speculate that the fixed field of vision in the present experiments may have added to this advantage of the self-contained movement condition: In contrast to an actual driver/co-driver situation, participants in the observed movement condition were not free to look around, thus not being able to perceive and encode spatial information at their own pace. However, our consistent findings, which were resistant against our other manipulations, speak in favor of a genuine advantage of self-contained movement for the encoding of landmark knowledge.

The development of survey knowledge in active navigation depends on other factors than movement control. A manipulation of learning intention in Experiment 1 showed few if any effects, and it did not affect the differences in spatial learning between the self-contained and observed movement condition. We conclude that learning intention appears to be of minor relevance in active navigation. At the same time, self-contained movement resulted in better way-finding performance, but did not enable better performance in classic survey knowledge tasks such as a pointing and a sketching task, which is in line with previous research. Our research suggests that this may be a result of task difficulty, because manipulations of movement control, instruction specificity, and decision control elicited differences in survey knowledge as measured with an easier tour-integration task we used in Experiments 2-3. These experiments imply that in contrast to landmark knowledge, survey knowledge is not genuinely superior after self-contained as compared to observed movement. In Experiment 2, participants either instructed their partners or were instructed by their partners about the correct route with verbal landmark information only or with additional verbal survey information. An advantage of self-contained movement in tour-integration and way-finding depended on instruction control. Without instruction control, there were no significant advantages of self-contained over observed movement. In our interpretation, people in the self-contained movement condition were more able to integrate the additional information into a mental representation of the environment. In Experiment 3, the navigation instructions included an element of decision-making by using fragmented maps, in contrast to the unambiguous instructions of Experiment 2. In line with previous research, tour-integration performance was only affected by decision control, but not by movement control. More importantly, active decision-making enabled participants who observed movement rather than participants who controlled movement to compensate for disadvantages in way-finding performance. In sum, whereas information control (especially with additional survey information) increased the difference in spatial learning between self-contained and observed movement in Experiment 2, active decision-making in Experiment 3 decreased this difference.

These apparently contrasting effects can be interpreted as a result of the depth of encoding that was required in each experimental setting. More specifically, the instructions in Experiment 2 did not require deep encoding per se as they provided unambiguous information. Thus, participants who observed movement neither needed to elaborate the presented information, nor did they need to care about the transfer of this information into a navigational decision (i.e., in principle, they could have completed their part in the study phase by reading the instructions to their partner without looking at the computer screen at all). Participants in the self-contained movement condition were forced to put some effort into this transfer, which led to better interactive context encoding and consequently better spatial learning. This situation differed in Experiment 3, where the transfer of reading the map-based instructions to choosing a course in the environment needed to be made by all participants in the active navigation condition, regardless of controlling or observing movement. Consequently, active decision-making rather than movement control determined the development of survey knowledge. This reasoning could be further tested by implementing a verbal instruction (resembling Experiment 2) that requires participants who observe movement to process and transfer the instructions into a navigational decision. (Experiment 1 indicates that the intention to do so is not sufficient.) Unfortunately, such a condition is hard to conceive.

Some other aspects of the research at hand deserve discussion. First, moving from a verbal to a pictorial instruction format due to implementing decision control necessitated some changes that may have differently affected the experimental conditions. However, we cannot think of a satisfying explanation why the difference of verbal route instructions as compared to pictorial route instructions could have confounded the reported findings. Even if this were the case, this argument would not compromise our conclusion that self-contained movement does not lead to superior encoding of survey knowledge per se, but that other factors (i.e., instruction specificity and decision control) are crucial to this advantage. Another difference between the experiments was that all participants in Experiment 2 received some navigational information. Thus, Experiment 2 did not include a no-information condition (comparable to the no-navigation condition in Experiment 3) that would be needed in order to evaluate base-line performance in the different tasks unbiased by instruction information. Such a condition would have allowed additional insight especially into the development of landmark knowledge. However, findings concerning landmark knowledge were quite clear in the present set of experiments, with a genuine advantage for the self-contained movement condition. Therefore, we consider it a minor drawback of the present set of studies that this condition was missing in Experiment 2.

A second aspect to discuss is that we tested spatial knowledge of a specific route, in line with many studies that either used environments consisting of a single, pre-determined route (Brooks et al., 1999), or that instructed participants explicitly to think about a specific route they would use (Carassa et al., 2002; Farrell et al., 2003). Most of these studies report an advantage of active navigation. In contrast, studies in which participants were instructed to make themselves generally familiar with an environment through free exploration found no active navigation advantage (Wilson, 1999; Wilson et al., 1997). Thus, an advantage of active navigation may depend on a specific route that has to be remembered. However, additional findings are inconsistent with this reasoning: Both advantages in spatial knowledge of active over passive navigation after free exploration of an environment have been found (Péruch et al., 1995), as well as comparable performance after actively versus passively learning a specific tour (Gaunet et al., 2001). Although the differences between route learning and free exploration are of theoretical interest, we chose a specific tour because this more closely controls what people are actually doing than an unspecific instruction to study an environment in general.

Third, the research at hand manipulated movement control as a central factor, ajar to driver/co-driver situations. However, it has been reasoned above that in the present experimental design, participants who observe movement are not only limited in movement, but also in their field of vision. Future research may attempt to enable a free field of vision for participants who observe movement in order to disentangle effects of movement control from potential effects of vision control.

2.5.1 Conclusion

In conclusion, the present findings provide evidence that self-contained movement leads to a genuine advantage in the development of landmark knowledge as compared to observed movement in route learning in complex virtual environments. However, advantages in the development of survey knowledge depend on the availability of instruction control (Experiment 2) and active decision control (Experiment 3), factors that are frequently, but not necessarily, entangled with self-contained movement. A survey knowledge advantage in active over passive navigation seems to depend on a mandatory elaboration of spatial information during navigation. Mere learning intention did not generate the needed depth of elaboration (Experiment 1). If the elaboration of survey information is mandatory also to people who observe movement, they are not disadvantaged in route learning to people who control movement.

3. Can Active Navigation Be as Good as Driving? A Comparison of Spatial Memory in Drivers and Co-Drivers

3.1 Introduction

One common way to get to know a new route in modern times is driving or co-driving a vehicle, with the driver, but not the co-driver, controlling movement. People often claim that it is easier for them to memorize a route when driving instead of co-driving. Independent of movement control, either of them may be responsible for navigation in the sense of decision-making (e.g., giving directions according to a map). With regard to navigation, a co-driver may merely be a passenger of a maneuvering and navigating driver; or a driver may only follow navigational instructions, the co-driver being active in controlling navigation. In each of these situations, a person might want to remember a route accurately. Although some studies have alluded to this topic, a direct comparison of different levels of movement control with different levels of navigation control in real environments has not been made. Thus, it is unclear whether the lay assumption that drivers have general and inherent advantages in spatial learning compared to co-drivers holds true. Experiment 3 provides evidence that the control of decisions is more important for spatial learning than the mere control of movement, a finding supported by other studies on active navigation in virtual environments (e.g., Farrell et al., 2003). In other words, if co-drivers navigate actively, their memory performance may be better than performance of passively navigating drivers. The present research aims to test the effects of movement control and navigation control on performance in different spatial knowledge tasks. Participants were asked to drive or co-drive on a tandem bike through a park environment, and active navigation was required, or not, by providing differently elaborated map segments.

3.1.1 Active Navigation

Route learning and navigation in a driver/co-driver situation resembles experimental settings in active navigation research. Central to active navigation research (which has been studied almost exclusively in virtual environments) is the idea that the active, self-directed, and free exploration of an environment enables superior spatial learning compared to a more passive, observing encounter of the same environment. However, whereas several studies support this assumption (e.g., Carassa et al., 2002; Hahm et al., 2007; Péruch et al., 1995; Wallet et al., 2008), a similar number of studies found few if any differences (e.g., Gaunet et al., 2001; Wilson, 1999; Wilson et al., 1997). Chapter 2 showed that two factors appear central to advantages of active over passive navigation, namely the type of spatial knowledge test applied and decision control, which are recapitulated below.

A review of studies comparing effects of active and passive navigation in virtual environments (Wallet et al., 2008) suggests that active navigation provides no advantage in classic survey knowledge tasks – such as pointing towards landmarks that are out of sight and sketching maps of the environment. In contrast, active navigation is found to elicit superior performance in free orientation tasks as more applied tests of survey knowledge. The evidence regarding landmark knowledge is mixed. Taken together, the type of spatial knowledge test applied influences whether active navigation appears superior to passive navigation. Thus, below we use the most common spatial knowledge tests.

In many cases, controlling the movement of a vehicle goes along with deciding about the course to be taken. However, this connection is not mandatory: a driver may depend on the navigational decisions of a co-driver, thus controlling movement, but not decisions. The importance of decision control for spatial learning has been emphasized in a number of studies on active navigation in virtual environments (Carassa et al., 2002; Farrell et al., 2003; Wilson et al., 1997, also see Experiment 3). Farrell and colleagues (2003) demonstrated that participants who had free control over movement but saw a red line on the floor indicating the optimal course through the virtual equivalent of a real environment showed the same transfer performance to the real environment as participants who passively watched a video clip presenting the same course through the maze. Only participants who were allowed to explore the virtual maze freely without the red line were superior to those in the other conditions in transferring the memorized course to the real environment. Thus, not the control of one's own movement, but active decision-making about the course led to better transfer performance. In conclusion, there is evidence that controlling the decision where to move is more important than the execution of this movement, but so far the evidence is limited to virtual environments. By implication, if drivers appear to learn routes easily, this may be due to the decisions that they take in order to reach their destination rather than due to their physical control of the vehicle (e.g., deciding to turn left rather than turning the steering wheel). In other words, this suggests that driving may have no genuine advantage for spatial learning as compared to co-driving, but is merely confounded with the control of decisions.

Only a few studies have alluded to active navigation in real environments. An early study found that people who commuted with their own cars draw more accurate maps of a city than people who used public transport (Appleyard, 1970). In a more recent study, Münzer and colleagues (2006) compared route and survey knowledge after participants had navigated on a pre-selected tour through a large-scale environment by either using map fragments or by using a mobile navigation device that presented route information. Participants in the map condition developed both better route and survey knowledge. This result is interpreted as more active navigation of map users: They needed more cognitive resources to memorize a segment of the tour and transfer this information to route choices in the actual environment, in contrast to mobile device users who followed instructions concerning the next turn. Thus, the authors discuss active navigation in terms of cognitive effort spent to elaborate navigation instructions of a pre-selected tour, rather than as an effect of deliberate choices in navigation. Given that the presentation format differed between the conditions, an alternative explanation cannot be excluded: map users studied survey information, whereas mobile device users studied route information, and the results may demonstrate that studying survey information is superior to route information. Another recent study (Willis et al., 2009) used more comparable presentation formats: participants learned an environment either by studying a map without actual exposure, or by direct navigation through the environment with a mobile map presented on a smart phone. None of the conditions allowed for choice in navigation. Map users showed better survey knowledge than mobile map users despite the latters' direct experience with the environment and more exposure time. One source of this effect that the authors identify is the passive interaction with the mobile map: using the mobile maps encouraged participants to pay less attention to navigation.

To summarize existing research: studies on spatial learning in virtual environments emphasize the role of decision control in active navigation (e.g., Farrell et al., 2003). A respective approach in a real environment has not been made to date, where studies that alluded active navigation put more stress on the idea that active navigation differs from passive navigation in terms of cognitive resources that are spent on the elaboration of navigational instructions (Münzer et al., 2006; Willis et al., 2009). Despite these differences, approaches in virtual and real environments converge on the idea that active navigation benefits spatial learning, and suggest that active decision-making is more central to spatial learning than active movement control.

3.1.2 Aims of Chapter 3

There is some evidence for the greater importance of navigation control in comparison to movement control for spatial learning in virtual environments, but there is to date no comparison of these factors in a real environment. Conceptualizations alluding active navigation in real environments are entangled with effects of different presentation modalities. In order to test how movement control and navigation control affect the acquisition of spatial knowledge, we set up a 2 × 2 experimental design combining driving and co-driving with active and passive navigation control. Using a tandem bike in a public park combined the advantages of locomotion and navigation in a real world setting while controlling exposure. In an adaption of Farrell and colleagues' (2003) approach of self-contained movement with or without additional indications of the optimal route in a virtual environment, active and passive navigation control was manipulated by presenting a fragmented map that had to be memorized (see Münzer et al., 2006, and Experiment 3 for a similar approaches). In the active navigation condition, the fragmented map was designed to induce planning and decision-making about the optimal course, but to guide participants unobtrusively on an intended course. Passive navigation was established by presenting the same fragmented map without the need to make decisions by adding information about the optimal course. This approach avoided fundamental differences in the presentation format between active and passive navigation.

We tested the effects of our experimental conditions on different levels of spatial knowledge, namely landmark knowledge with recognition tasks, and survey knowledge with free orientation tasks and tour-integration tasks, the latter testing the ability to mentally combine the fragmented map into a representation of the whole tour. However, the research on goal specificity emphasizes that spatial learning is developed contingent on available information (Taylor et al., 1999): individuals who studied maps of a virtual environment were superior in survey tasks, whereas individuals who navigated through the environment gave more accurate responses in route perspective tasks (see also Fields & Shelton, 2006; Rossano & Reardon, 1999; Shelton & McNamara, 2004). For the present study, this implied that by using maps for navigational instructions, people were likely to be inclined towards a survey-based representation of the environment and rather deflected from encoding landmark information. Thus, tasks related to a map-oriented representation were of most interest: If active decision-making about the correct course is more relevant for spatial learning than the execution of this decision as implied by active navigation research, we can expect better performance in these tasks after active than after passive navigation, but no advantage of drivers over co-drivers. Existing findings regarding landmark knowledge in virtual environments are mixed, thus we attempted to explore further whether manipulations of movement control affect landmark knowledge in real environments. The more participants are required to elaborate the map-based instructions, the more they could be distracted from processing landmark information. Thus, we expected that participants in an active navigation condition might show worse landmark knowledge than participants in a passive navigation condition.

3.2 Experiment 4

As one might expect, environment familiarity affects spatial memory (Foley & Cohen, 1984; Iachini, Ruotolo, & Ruggiero, 2009; Kirasic, Allen, & Siegel, 1984). Thus, we reasoned that the experimental manipulations would show the largest effects on the performance of naïve participants, and tested a sample of first year students who were mostly unfamiliar with the environment. Landmark knowledge was measured with a landmark recognition task, survey knowledge with a free orientation task and with the ability to integrate the navigational instructions into a mental representation of the complete environment with a tour-integration task.

3.2.1 Method

3.2.1.1 Participants

Given $\alpha = .05$ and a statistical power of $1 - \beta = .80$ (Cohen, 1977), detecting large differences between two independent means ($d = 0.80$) required $N = 52$ (Faul, Erdfelder, Buchner, & Lang, 2009). Participants were 62 first year students (15 of them male; age: 18-25, $M = 20.16$, $SD = 1.68$). About two thirds of them ($n = 43$) had moved to the city within two weeks before participating in the experiment and 47 participants stated that they had never been in the park environment before.

3.2.1.2 Design

Independent variables were movement control (driver vs. co-driver) and navigation control (active vs. passive), manipulated between subjects. Dependent variables were landmark recognition, free orientation, and tour-integration.

3.2.1.3 Materials

Tour & Map Preparation. The experiment took place in a major park area close to the city centre. The park is pervaded by asphaltic and gravel roads only used by pedestrians and bikers. We created a six-segment tour through the whole park, displayed in Figure 5 (see Münzer et al., 2006; Zimmer, 2004, for similar approaches). The tour had an approximate length of 3500m with segments of about 300m to 800m.

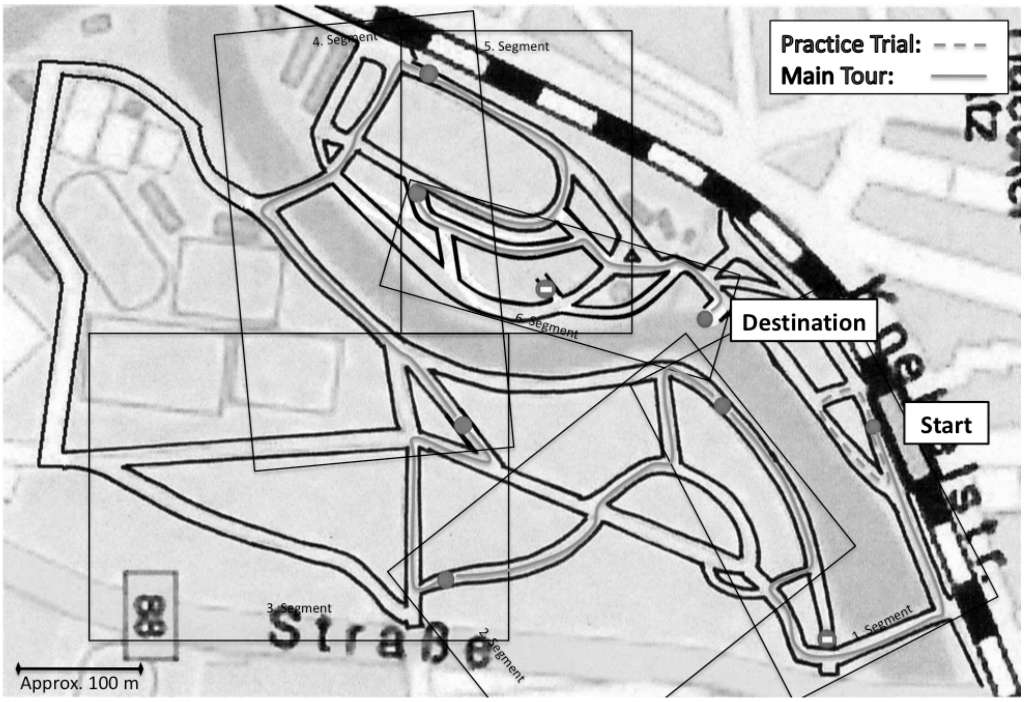

Figure 5. Tour through the park environment in Experiment 4. The dotted line marks the practice trial, the continuous line displays the actual course. Dots mark the starting point, the end of each course segment and the final destination. All six map segments as they were presented to the participants are indicated with black squares.

We prepared Din A4 color prints of each map segment, with small areas of overlap with other segments. Each segment contained a clear indication of the starting point and the destination, as well as all paths and intersections connecting these places. Each segment was carefully developed to ensure that there was only one unambiguous shortest connection between the starting point and the destination within a respective segment, although at least two different courses were possible. This shortest connection contained between 3 and 5 crossings where a decision about the course to be taken was necessary.

Participants received one map segment at a time. In the active navigation condition (see Figure 6), only starting point and destination were marked with red dots. Participants were asked to memorize and ride the shortest possible way on roads. Thus, they were required to choose the optimal course among several possible ones. Due to the composition of the map segments and the instruction, they actively elaborated the map segments, but were unobtrusively guided on the course we had intended. Participants in the passive navigation condition received identical map segments, but the shortest way was marked with a blue line (see Figure 6). In addition, every crossing was marked with a number, which corresponded to a small photo of this crossing on one side of the map segment. Thus, participants in the passive navigation condition clearly received *more* information than those in the active navigation condition, which should lead to *less* decision making about the optimal course and thus less survey knowledge.

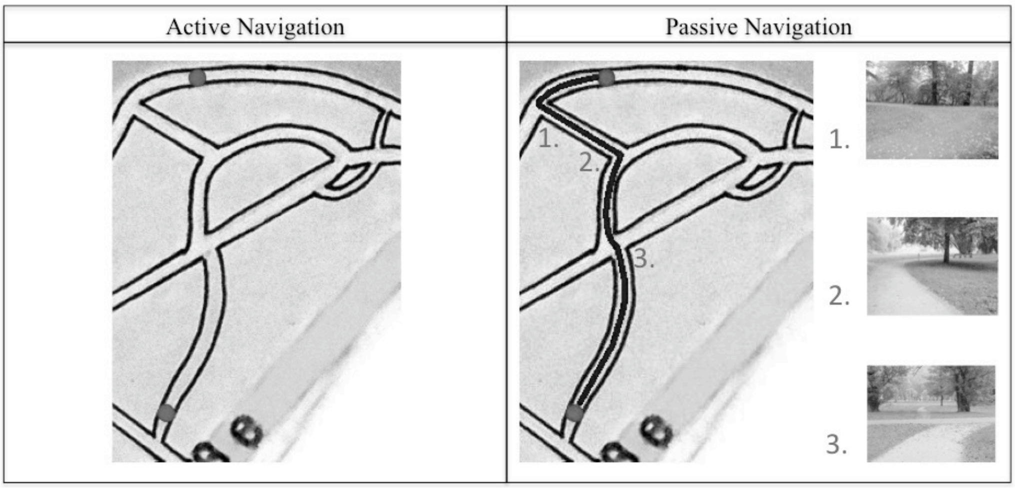

Figure 6. Map segment 2 as it was presented to the participants in all experiments of Series 1. In the active navigation condition, only start and destination were included. In the passive navigation condition, a line indicated the optimal course between start and destination, and a number referred to a small image of each crossing presented on one side of the map segment.

Landmark Recognition. As an indicator of landmark knowledge, we prepared a recognition task with six unique landmarks encountered on the tour (e.g., a pump station, a public barbecue place, and a memorial stone) and six comparable distractors from the park environment not encountered on the tour. None of these landmarks was visible on the photos on the passive navigation map segments. Participants received pictures of all landmarks in quasi-randomized order, and were asked to mark whether they had seen each landmark on their tour or not[2].

Free Orientation. We attempted to test participants' survey knowledge with their ability to identify and use novel shortcuts on a return tour. The first starting point and the final destination were in line of sight; hence we included a stopover at a major landmark, a bridge in the middle of map segment 4 (see Figure 5). Participants were first asked to ride to this bridge and then back to the start on the shortest route with a tachometer recording the distance in meters. The shortest possible return path was about 1500m long.

Tour-integration. As in Experiment 2-3, participants received a complete but blank map of the park in order to test their ability to transfer the map segments they had received one by one into a mental representation of the whole tour (see van Asselen et al., 2006, for a similar approach). That is, they received the map that can be seen in Figure 5 with the marked indications of the start and the final destination, but without indications of the map segment outlines, the destinations, or the actual tour. They were instructed to draw in the route they had cycled before. This tour-integration task requires correct memory of the course of each segment. The map segments need to be located on the complete map, therefore they need to be recalled in correct order and mentally rotated. This task requires aspects of both route knowledge (remembering the correct order) and survey knowledge (positioning the map segments in correct relation to each other). Moreover, it resembles real-life orientation situations, where someone initially only possesses fragmented navigation information, but wants to reconstruct the whole tour. Evaluation of tour-integration performance required a slightly different computation than in the first series and was evaluated by scoring one point

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[2] Originally, the landmark recognition task was followed by a pointing task as an additional classic measure of survey knowledge. Participants received a sheet which indicated the degrees from 0° to 180° in steps of 5 in a semicircle. The experimenter took care that body position and the sheet orientation were constant for all participants. Participants were shown the original six landmarks and asked to estimate their direction in degrees. The mean, absolute deviation from the correct degrees was computed and entered into a 2 × 2 ANOVA. Performance was bad in general ($M = 45°$, $SD = 21$) and did not differ between the experimental groups (all Fs < 1). Thus, consistent with findings in virtual environments, a pointing task in a real environment appeared insensitive to manipulations of active navigation (see Wallet et al., 2008, for an overview), and we refrained from using a pointing task in the following experiment.

for every two crossings of the original tour that a participant connected correctly (perfect performance: 24 points).

3.2.1.4 Procedure

Participants were tested individually and did a short practice ride of about 300m with the experimenter to get used to riding the tandem (this practice ride is also depicted in Figure 5). After returning to the start, instructions were given in written and oral form: “You will learn a route through the park environment. This route consists of six segments. For each segment, you will receive a map with a starting point and a destination. Identify the shortest route between them. Memorize the map segment! Your memory for the learned route will be tested later. Try to remember the whole route!” Depending on condition, the participant was handed the active or the passive version of the first map segment for about 30 seconds and either seated on the front or back seat. The experimenter indicated the markings of start and destination on each map segment to the participant. The experimenter took back the map, and they started towards the first destination. The destination points were positioned in the middle of path segments rather than at crossings in order to increase the overall number of crossings on the route. Thus, although the general area of a destination point was obvious, the exact position was not. In order to hold the destination points constant across all participants, the experimenter took care that the tandem stopped at the exact destination of each segment for all participants.

Driving participants were asked to announce the direction at crossings. This procedure was repeated for all six segments. If a participant announced a wrong direction, the tandem was stopped and the participant was allowed another short view of the current map segment. The tour was completed in M = 11min 51sec (SD = 1min 35sec). Participants made $M = 1.71$ ($SD = 1.05$) wrong decisions, with no significant main or interaction effects of driving position, navigation, and environment knowledge, all Fs < 1.37.

After arriving at the final destination, participants responded to an unrelated questionnaire for about two minutes to avoid recency effects. Then, the landmark recognition task was administered, followed by the tour-integration task. In a short questionnaire including demographic questions, participants were asked how many times that had been in the park environment on a scale from 1 (never) to 5 (very often), and to estimate their experience with tandem riding on a 5-point scale. In the final free orientation task, all participants took place on the front seat and were asked to ride the shortest way first to the bridge and then back to the start. The experiment took about 45 minutes.

3.2.2 Results

3.2.2.1 Preliminary Analyses

Most participants had no experience riding a tandem, *M* = 1.24, *SD* = 0.62. Environment knowledge was very low, *M* = 1.40, *SD* = 0.86. We checked for potential confounds of these factors by entering them as dependent variables into 2 (movement control: driver vs. co-driver) × 2 (navigation control: active vs. passive) ANOVAs. There were no significant main effects or interactions, all *F*s < 1, with the exception of a non-significant advantage of co-drivers over drivers regarding tandem experience, *F* = 3.55, *p* = .07. There were no gender differences for any of the dependent variables, all *F*s < 1. Descriptive statistics of all dependent variables are presented in Table 4.

3.2.2.2 Landmark Knowledge

We computed PR scores for participants' ability to discriminate encountered from non-encountered landmarks (hits minus false alarms, see Snodgrass & Corwin, 1988). The data suggest that drivers did not develop better landmarks knowledge than co-drivers, but landmark recognition was better after passive than after active navigation. Accordingly, the ANOVA showed a main effect of navigation, $F(1,58) = 5.54$, $R^2_p = .09$, but no other effects, all *F*s < 1. Apparently, participants who concentrated more on the encoding of the map segments were less attentive to their surroundings.

Table 4. Descriptive Proportions of the Landmark Recognition Task and the Tour-Integration Task, and Descriptive Values in Meter for the Free Orientation Task in Experiment 4, Separately for All Experimental Conditions.

Task	**Drivers**		**Co-drivers**	
	Active Navigation	**Passive Navigation**	**Active Navigation**	**Passive Navigation**
Landmark Recognition:	.17 (.29)	.33 (.27)	.17 (.30)	.33 (.24)
Free Orientation:	1643m (81)	1687m (179)	1669m (146)	1704m (198)
Tour Integration:	.83 (.15)	.75 (.25)	.80 (.20)	.73 (.29)

3.2.2.3 Survey Knowledge

Free Orientation. The average travelled distance in this task showed little variance between the experimental groups: Participants across all experimental groups were able to use an efficient return path without many detours. Consequently, there were no main or interaction effects in the free orientation task, all *F*s < 1.

Tour-integration. As we expected, the analysis revealed the expected main effect of navigation, $F(1,57) = 5.39$, $R^2_p = .09$: participants in the active navigation condition performed better in the tour-integration task than participants in the passive navigation condition (other Fs < 1.23).

3.2.3 Discussion

In line with our assumptions, navigation control affected spatial learning: Active encoding of map segments led to a better mental representation of the whole tour than passive encoding, but distracted participants in the active navigation condition from memorizing landmarks, as indicated by their worse landmark recognition performance. In contrast, there were no effects of movement control: Neither did drivers recognize more landmarks correctly, nor did they perform better in the tour-integration task or choose a more efficient return route in the free orientation task compared to co-drivers.

Unfortunately, there was little variance in the free orientation task: almost all participants chose a very efficient return course. Two external factors may have contributed to this result. First, all participants had received a complete map of the park environment in the previous tour-integration task. Second, the park environment is rather clearly arranged and open-spaced (in contrast to complex buildings, see Hölscher, Meilinger, Vrachliotis, Brösamle, & Knauff, 2006). Thus, working with the complete map just before this task and orienting by sight was obviously sufficient to perform well in the free orientation task.

Experiment 4 closely resembles a scenario of navigating through an unknown city. According to our findings, in such a situation, being the driver does not seem to be as advantageous as is widely believed. Yet, this conclusion has two limitations: First, although the tour-integration task contained some elements of route knowledge, the experiment missed a traditional measure of route knowledge such as a landmark-ordering task. It is possible that drivers are more inclined to memorize a route in terms of the temporal order of landmarks. Second, it is unclear whether movement control as a driver may be more advantageous in case of a somewhat familiar environment.

3.3 Experiment 5

Experiment 5 aimed at extending the findings of Experiment 4 to a sample of participants with more familiarity with the environment. One might fear that given environment knowledge, effects of the experimental conditions could not be detected (Foley & Cohen, 1984; Iachini et al., 2009; Kirasic et al., 1984). In contrast, effects of movement control may become more important: Given that orientation and navigation need fewer resources in a familiar environment, drivers may be more able to attend to their surroundings than co-drivers due to sitting position and movement control, giving them some advantages to memorize spatial information encountered on the tour.

As an unambiguous measure of route knowledge, we included a landmark-ordering task. This task requires the recall of the temporal order of appearance of landmarks, and may provide additional insights into the acquisition of spatial knowledge: If drivers rely more on the temporal ordering of landmarks than co-drivers to remember a route, this task is suitable to detect such a preference. Again we expected that active navigation might support performance in the tour-integration task, but inhibit the recognition of landmarks.

3.3.1 Method

The method corresponded to Experiment 4 with the following exceptions.

3.3.1.1 Participants & Design

We found effect sizes of about $R^2_p = .10$ (corresponding to $d = 0.66$) in Experiment 4. With $\alpha = .05$ and a statistical power of $1 - \beta = .80$ (Cohen, 1977), $N = 73$ was required to detect effects of this size. Participants were 70 students (20 males), most of them in their third or fourth semester. None of them had participated in Experiment 4. Age ranged from 19 to 38 years ($M = 22.07$, $SD = 2.97$). Five participants who misunderstood either the tour-integration task and/or the landmark-ordering task, and whose performance was far below average (-2 *SD*s), were excluded from further analyses. Thus, $N = 65$ remained. Independent variables were movement control (driver vs. co-driver) and navigation control (active vs. passive), manipulated between subjects. Dependent variables were landmark recognition, landmark ordering, and tour-integration.

3.3.1.2 Materials & Procedure

We created another five-segment tour of about 3000m with segments between 300m and 950m, comparable to the tour depicted in Figure 5. After arriving at the final destination, participants solved math equations for about 2 minutes as a distractor task before working on the tasks in the order described below.

Landmark Recognition & Landmark Ordering. Twelve landmarks were used for landmark recognition and ordering. In the recognition task, participants received either one half or the other half of the original landmarks and six distractor landmarks in quasi-randomized order, and were told to indicate whether they had encountered a landmark on the tour or not. In the subsequent landmark-ordering task, participants received a booklet with pictures of all twelve original landmarks in a quasi-randomized order, each marked with a random letter. Participants were asked to write down these letters in the order in which they had encountered the landmarks on the tour. If a letter was arranged in the correct position (e.g., the letter of the landmark encountered third was placed in the third position), two points were scored. If a landmark was arranged in an adjacent position (e.g., the same letter was placed in the second or fourth position), one point was scored. Perfect ordering corresponded to 24 points.

Other Measures. Performance in the tour-integration task was computed as in Experiment 4. Perfect performance corresponded to 20 points. After completing this task, participants estimated their experience with tandem riding and knowledge of the park environment on a 5-point scale. To validate the latter rating, they were also asked how many times they had been in the park environment on a scale from 1 (never) to 5 (very often). We intended to assess survey knowledge with a free orientation task as in Experiment 4, but assumed that high environment knowledge might render this task invariant: It seemed unlikely that participants familiar with the park would make more mistakes in this task than the naïve participants in Experiment 4. This suspicion was confirmed: After 14 participants had chosen the same return path ($M = 814$m, $SD = 24$) this task was dropped.

3.3.2 Results

3.3.2.1 Preliminary Analyses

Knowledge of the park environment was average ($M = 3.06$, $SD = 1.03$), and so were participants' reports how often they were in the park environment ($M = 3.03$, $SD = 1.06$). The measures correlated significantly, $r = .59$, underlining the validity of these estimates. Again, most participants had little experience in riding tandems, $M = 1.32$, $SD = 0.73$. ANOVAs with the dependent variables environment knowledge and tandem experience showed no significant effects of movement control or navigation, all Fs < 1.50. Gender had no significant effects on the dependent variables, all Fs < 1.65.

3.3.2.2 Landmark & Route Knowledge

Landmark Recognition. PR scores (hits minus false alarms, see Table 5) indicated that drivers showed better landmark recognition than co-drivers, but there was little difference between active and passive navigation. This impression was corroborated in the 2 × 2 ANOVA that showed a main effect of movement control, $F(1,61) = 4.77$, $R^2_p = .07$ (all other

*F*s < 1). This finding contrasts Experiment 4, where naïve participants recognized more landmarks when navigating passively, but not when being the driver. An explanation for these contrasting effects could be that an inhibiting effect of active navigation on landmark knowledge is limited to participants unfamiliar with an environment. To test this assumption, we additionally analyzed the recognition data of those 23 participants in Experiment 5 who rated their environment knowledge below 3 on the 5-point scale. We refrained from a statistical analysis of these data due to the small *N*, but the descriptive values are in line with our interpretation: The advantage of drivers (*M* = .30, *SD* = .23) over co-drivers (*M* = .23, *SD* = .37) was diminished, whereas passive navigation (*M* = .32, *SD* = .34) allowed distinctively better recognition than active navigation (*M* = .15, *SD* = .24). Thus, the data pattern of the participants least familiar with the environment in Experiment 5 was similar to that of Experiment 4.

Table 5. Descriptive Proportions of the Landmark Recognition Task and the Landmark-Ordering Task in Experiment 5, Separately for All Experimental Conditions.

	Drivers		**Co-drivers**	
Task	**Active Navigation**	**Passive Navigation**	**Active Navigation**	**Passive Navigation**
Landmark Recognition:	.43 (.28)	.36 (.28)	.22 (.22)	.24 (.31)
Landmark Ordering:	.66 (.14)	.59 (.16)	.58 (.17)	.61 (.17)

Landmark Ordering. There was no indication that drivers relied more on route knowledge than co-drivers (see Table 5). All experimental groups showed comparable performance in the landmark-ordering task (all *F*s < 1.33). Performance averaged *M* = .61, *SD* = .16, indicating that the interpretation of this task was not limited by floor or ceiling effects.

3.3.2.3 Survey Knowledge

As can be seen in Figure 7, performance scores in the tour-integration task indicate that passive co-drivers showed noticeably worse performance than the other groups. There was no main effect of navigation, *F* = 1.16, but a main effect of movement control, *F*(1,61) = 4.75, R^2_p = .07. More importantly, this was qualified by an interaction of both factors, *F*(1,61) = 4.13, R^2_p = .06. A planned Helmert contrast was the most powerful statistical test to determine whether passive co-drivers who lacked control of movement as well as active elaboration of the map-segments were indeed inferior to all other groups in the tour-integration task. Thus, passive co-drivers (coded -3) were contrasted against the other three conditions (each coded 1). This contrast was significant, *F*(1,60) = 3.65, $R^2_p = .15$. Passive co-drivers (*M* = .72, difference estimate = -3.43, 95% confidence interval: -5.55 to -1.31) showed worse performance than those in the other conditions (average *M* = .89). No other contrasts were significant (all *p*s > .50). Thus, active movement control, active navigation, or the combination of both enabled participants familiar with the environment to develop an equally good mental representation of the whole tour.

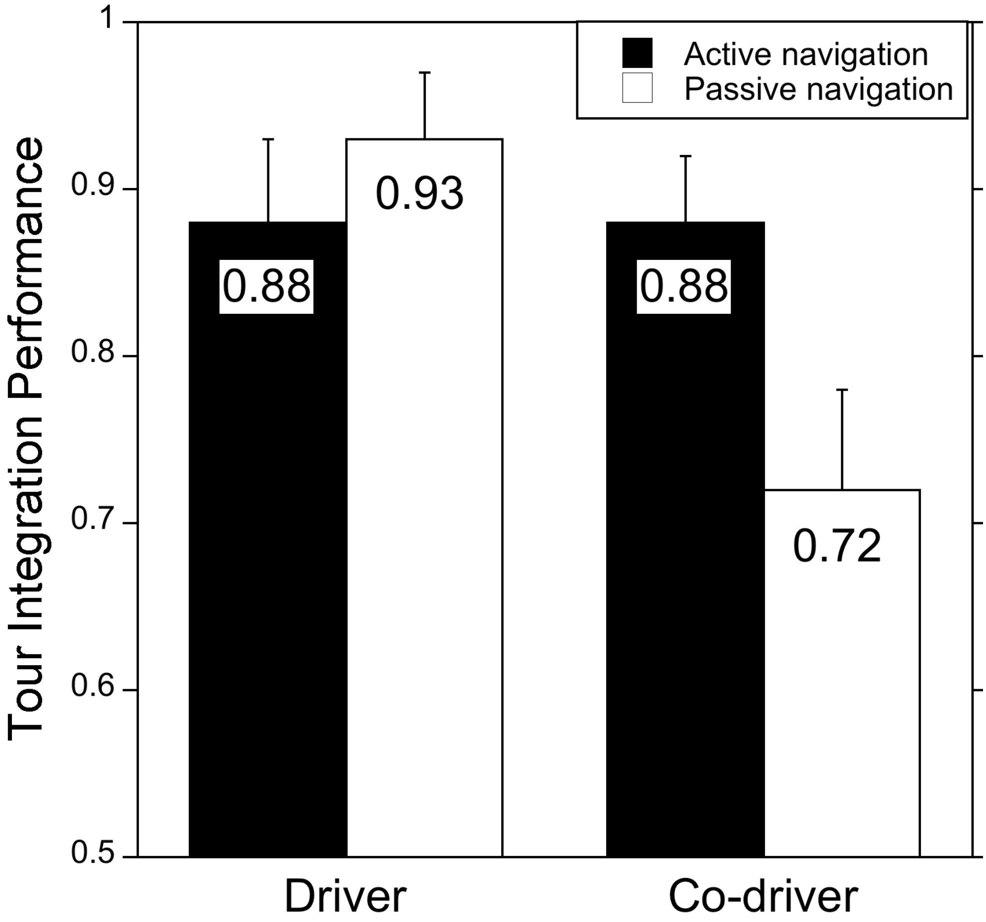


Figure 7. Average performance proportion in the tour-integration task in Experiment 5, separately for each experimental condition. Error bars represent standard errors of means.

3.3.3 Discussion

The most important finding of Experiment 5 is the interaction of movement control and navigation control in the tour-integration task: Both active navigation and driving enabled participants to develop a good mental representation of the tour, whereas the performance of passive co-drivers was noticeably worse. We interpret this finding as follows: For participants who were familiar with the environment, movement control helped drivers to compensate for the disadvantage of navigating passively. Only participants who neither drove actively nor navigated actively suffered significant performance losses in this task. This finding also implies that even for participants familiar with the environment, effects of movement control and navigation control on tour-integration performance are not additive: drivers in the active navigation condition were not superior to co-drivers in the active navigation condition or drivers in the passive navigation condition.

Regarding landmark knowledge, there were no differences between active and passive navigation, and drivers showed better recognition than co-drivers. Thus, given some familiarity with the environment, active navigation did not inhibit the perception and processing of landmarks as in Experiment 4, but movement control became more relevant. However, this advantage of drivers over co-drivers did not extend to route knowledge, measured with the landmark-ordering task: Although drivers recognized more landmarks than co-drivers, they did not use the temporal order of these landmarks to memorize the route.

To conclude, if the environment is already familiar, drivers appear to have some advantages in the acquisition of landmark knowledge. This finding is in line with some (e.g., Hahm et al., 2007), but not all active navigation studies on landmark knowledge in virtual environments (e.g., Gaunet et al., 2001; Wilson, 1999). Drivers were also able to compensate for passive navigation in the tour-integration task. Yet, their route knowledge and their tour-integration were not superior to co-drivers. Thus, Experiment 5 is congruent with Experiment 5 in demonstrating that drivers do not possess advantages per se in the memorization of a specific tour.

3.4 Experiment 6

There are two potential limitations of the reported findings. First, our interpretations rely heavily on the tour-integration task as a sole indicator of survey knowledge. Although such a task has been used before (van Asselen et al., 2006), a validation with more established measures seems appropriate. Second, it is possible that participants in the passive navigation condition simplified the map segments to a route-based representation of the course, whereas participants in the active navigation condition established a survey-based representation. In other words, despite our attempt to keep the presentation format as similar as possible between both conditions, different representations may have been encouraged. Previous research has shown that even small differences between study conditions can elicit different mental representations of an environment (see Reagan & Baldwin, 2006; Willis et al., 2009).

Given qualitatively different mental representations, differences in our tour-integration task may indicate that a survey-based representation exceeds a route-based representation rather than better encoding due to active navigation.

To address these issues, participants in Experiment 6 were required to study map-based instructions without actual exposure to the environment. If participants in the active and passive navigation condition develop different mental representations of the map segments, we expect “active navigation” to provoke sketches of survey-based drawings and “passive navigation”, route-based drawings after studying a map segment. In turn, if the mental representation affects the tour-integration task, performance in this task must be the worse the more someone tends to a route-based representation of the map segments.

Additionally, one may expect better performance after active compared to passive navigation if active navigation leads to better elaboration of the map instructions (either due to decision control or due to a more survey-based representation). In contrast, it is possible that the effect vanishes because studying the map segments in a laboratory setting does not involve actual navigation. Tour-integration performance should be generally lower than in the previous experiments due to the absent environment exposure.

In order to validate the tour-integration task, we use a free map-drawing task and a spatial indication task (see for example Münzer et al., 2006). If the tour-integration task is a valid measure of survey knowledge, we can expect to find substantial correlations among measures.

We also test whether environment knowledge affects the mental representation of the tour as well as performance in the other tasks by comparing participants with no respectively some environment knowledge. Possibly, familiarity with the environment may go along with increased reliance on a survey-based representation (Foley & Cohen, 1984; Iachini et al., 2009; Kirasic et al., 1984). An advantage of environment familiarity in all dependent variables can be expected if participants with environment familiarity are more able to transfer the studied map segments on to the environment.

Given the abstract setting, individual spatial abilities could influence findings. We account for this possibility by including a short spatial perception test.

3.4.1 Method

3.4.1.1 Participants & Design

We collected data of 100 participants (75 of them women). None of them had participated in the other experiments. Age ranged from 18 to 38 years (*M* = 21.67, *SD* = 3.29). Independent variable was navigation control (active vs. passive), manipulated between subjects; environment knowledge (naïve vs. familiar participants) was treated as the second factor. Dependent variables were tour-integration, sketch maps of the studied map segments, map drawing, and spatial indication.

3.4.1.2 Material & Procedure

Participants were tested in groups up to six persons, individually seated and separated by blinds between them. The experiment started with a subscale of the *Leistungsprüfsystem* (LPS, Horn, 1983) as an indicator of spatial perception ability. In this task, the number of surfaces of 39 partially visible geometric objects is to be identified within 3 minutes.

Participants were instructed that they would subsequently study six maps displaying a continuing route through a park. They were told to identify and memorize the shortest way on each map segment, and that their memory for the complete route would be tested afterwards. The map segments were identical to Experiment 4 with one exception: To facilitate the mental integration of the map segments despite the abstract study situation, letters were added to the starting point and destination on every map segment (that is, A and B on segment #1, B and C on segment #2, etc.). Participants received a map segment (the active or passive version) for 30 seconds. Then, the map segment was exchanged for a blank letter-size sheet of paper and participants were told: “Draw a sketch of what you have just memorized! You have 60 seconds.” This procedure was repeated for all map segments.

An unrelated two-minute questionnaire served as a subsequent distractor task. Then, participants received another sheet of paper and were told to draw the entire tour within three minutes. To avoid floor effects, the outlines of the river, the rail tracks, and start and final destination were indicated. Performance in the free map-drawing task was evaluated by scoring one point for every recognizable shape of the intended course of each map segment and one point, respectively, for crossing the river first on the right side of the map and crossing it back on the left side. Thus, a total of eight points could be obtained.

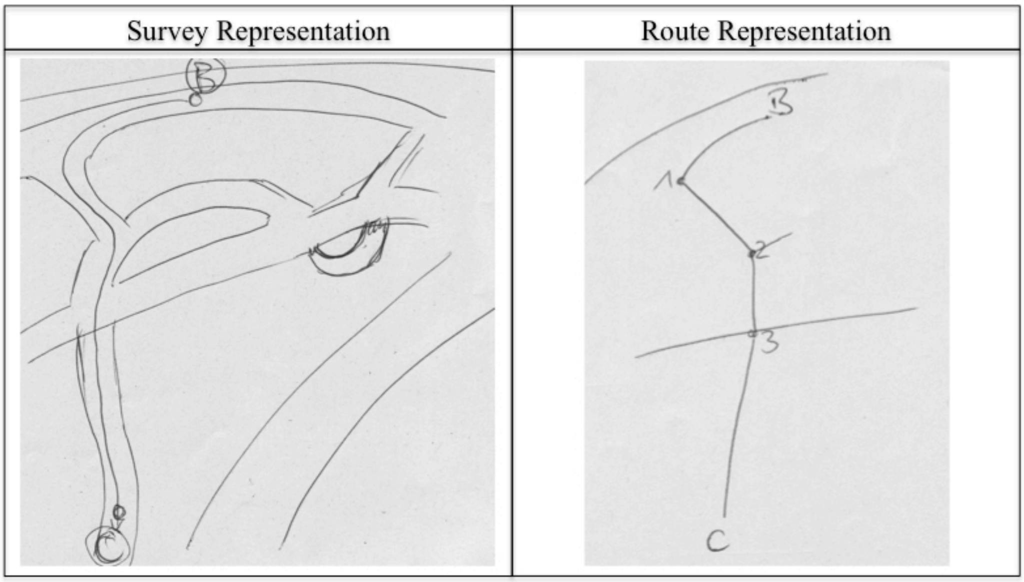
The tour-integration task followed where participants drew the path taken into a map. Subsequently, participants received another copy of the map for the spatial indication task and were instructed to mark the letters A to G (as indicated on the studied map segments) in the correct places within two minutes. Performance was evaluated by the average distance between the marked and the original position of each letter, smaller values indicating better performance. A demographic questionnaire and a 5-point scale for frequency of park environment visits followed these tasks. The experiment took about 30 minutes.

3.4.2 Results

3.4.2.1 Preliminary Analyses

The naïve group consisted of 39 participants who had never visited the park environment. The familiar group was formed by 61 participants who rated their knowledge 2 or higher ($M = 2.56$, $SD = 0.87$). There were no gender differences for any of the dependent variables, all Fs < 1. Spatial perception ability was computed by subtracting the number of wrong answers from the number of correct answers.

Map sketches were classified as displaying a route-representation or a survey-representation of the respective map segment. A route-representation was assumed if only the outline of the course on a respective map segment was drawn (even if some intersections were additionally denoted). A survey-representation was assumed if the sketch map included indications of environment features (e.g., the river) or the road system (e.g., intersections that were not part of the shortest path). Examples for both representations are presented in Figure 8.



Survey Representation

Route Representation

Figure 8. Examples of a survey-based representation and a route-based representation of map segment 2 in the sketch-map task of Experiment 6.

If it was impossible to assign a map sketch unambiguously to one representation, this map sketch was not scored. There was distinctively more ambiguity in map sketches of the first segment (54 ambiguous sketches) compared to the following five sketches (between 20 and 40 ambiguous sketches). Thus, we excluded the sketches of the first segment from further analysis. We summed up the route-representation sketches and the survey-representation sketches of the second to sixth map segment of each participant and computed a relative measure by subtracting the number of route-representation sketches from the number of survey-representation sketches. This resulted in scores from 5 (continuous sketching of survey maps) to -5 (continuous sketching of route maps), $M = -1.08$, $SD = 3.02$.

3.4.2.2 Correlation Analysis

We computed bivariate correlations among all dependent variables and the spatial perception ability test. All data were coded so that higher scores indicate better performance. The results are depicted in Table 6. (Correlation analyses computed separately for active and passive navigation as well as high and low environment knowledge display comparable results.) Spatial perception ability correlated with map drawing, tour-integration, and spatial indication: Higher abilities indicated better performance. In order to account for these correlations, spatial perception ability was taken into account as a covariate in the respective ANOVAs.

Table 6. Bivariate Correlations of All Dependent Variables and Spatial Perception Ability in Experiment 6.

	Sketch Maps	Map Drawing	Tour Integration	Spatial Indication
Spatial Perception Ability	.07	.29*	.33*	.23*
Sketch Maps		.08	.16	.24*
Map Drawing			.52*	.43*
Tour Integration				.60*

Note: * = $p < .05$. All Variables were coded to indicate higher values for better performance.

Tour-integration performance correlated significantly with map drawing performance and spatial indication, underlining the validity of this task. There was no significant correlation of tour-integration performance and sketch map representation: Performance in the tour-integration task was unrelated to the type of representation of the map segments, indicating that navigation effects in the tour-integration task can not be attributed to different encoding strategies. This was also true for the map drawing task, but not for spatial indication: participants tending to a more survey-like representation showed better spatial indication.

3.4.2.3 Sketch Maps

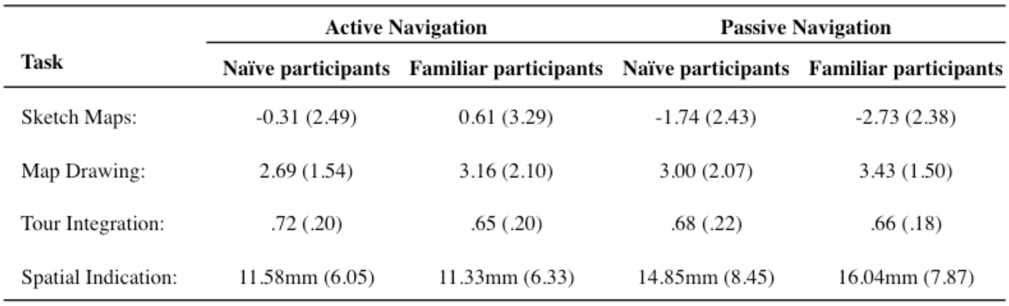
Descriptively, sketch maps differed between the active and passive navigation conditions (see Table 7 for all dependent variables). A 2 (navigation control: active vs. passive) × 2 (environment knowledge: naïve vs. familiar) ANOVA corroborated this impression, $F(1,96) = 17.93$, $R^2_p = .16$. Passive navigation clearly led to a route representation of the map segments, but there was no predominant representation after active navigation. There was no effect of environment knowledge, $F < 1$. Whereas the depicted data suggest that environment familiarity made participants rely more on a route representation after passive navigation and somewhat more on a survey representation after active navigation compared to naïve participants, the interaction was not statistically significant, $F = 2.90$, $p = .09$. Taken together, the active and passive versions of the map segments did affect the mental representation in contrast to our intentions. However, the correlation analyses indicated that not all tasks were confounded by this difference.

3.4.2.4 Survey Knowledge

Map Drawing. Overall, the quality of the map drawings was rather low, $M = 3.13$, $SD = 1.83$. We included spatial perception ability as a covariate in the 2 × 2 ANCOVA. (The linear relationship between covariate and the dependent variable as well as homogeneity of regressions was confirmed for all dependent variables.) Spatial perception ability was a significant covariate, $F(1,93) = 8.12$, $R^2_p = .08$. However, there were no main or interaction effects, all Fs < 1.02, in line with previous studies that used map drawing tasks to detect effects of active navigation. This suggests a floor effect elicited by the difficulty of this task.

Tour-integration. Spatial perception was a significant covariate of tour-integration performance, $F(1,92) = 5.45$, $R^2_p = .06$. Descriptively, there was a small advantage of active over passive navigation, replicating the previous experiments. Yet, this difference was not significant in the 2 × 2 ANCOVA, $F < 1$. Surprisingly, naïve participants performed somewhat better in this task than participants familiar with the environment, $F(1,92) = 3.77$, $R^2_p = .04$. The difference between active and passive navigation was larger for naïve than for familiar participants, but there was no interaction, $F < 1.72$. Thus, in contrast to the previous experiments, studying the map segments resulted in comparable performance after active and passive navigation. This implies that exposure to the environment is critical to elicit effects of navigation control in this task.

Table 7. Descriptive Values of All Dependent Variables in Experiment 6, Separately for All Experimental Conditions.



Task	Active Navigation		Passive Navigation	
	Naïve participants	**Familiar participants**	**Naïve participants**	**Familiar participants**
Sketch Maps:	-0.31 (2.49)	0.61 (3.29)	-1.74 (2.43)	-2.73 (2.38)
Map Drawing:	2.69 (1.54)	3.16 (2.10)	3.00 (2.07)	3.43 (1.50)
Tour Integration:	.72 (.20)	.65 (.20)	.68 (.22)	.66 (.18)
Spatial Indication:	11.58mm (6.05)	11.33mm (6.33)	14.85mm (8.45)	16.04mm (7.87)

Notes: Sketch map performance ranges between -5 (continuous route representation) and 5 (continuous survey representation). Map drawing performance ranges between 0 and 8 (higher values indicate better drawings). Proportion of correctly indicated paths is reported for the tour-integration task. Average deviation between the indicated and original positions of the letters A to G is reported for the spatial indication task.

Spatial Indication. When evaluating spatial indication, the covariate spatial perception ability was significant, $F(1,92) = 7.29$, $R^2_p = .07$. Moreover, the 2 × 2 ANCOVA indicated significantly better spatial indication after active compared to passive navigation, $F(1,92) = 8.51$, $R^2_p = .09$ (both other $Fs < 1$). Thus, this task appeared more sensitive to our manipulation of navigation control than the tour-integration task.

3.4.3 Discussion

In Experiment 6, we attempted to validate the tour-integration task by adding two established measures of survey knowledge. Indeed, performance in this task correlated with performance in a free map drawing task and spatial indication, attesting to the validity of the tour-integration task for measuring survey knowledge. Thus, the tour-integration task displays a fast measure of survey knowledge that is easier to interpret than a free map-drawing task and less likely to produce floor effects.

Our second aim was testing whether lab participants developed different mental representations after "active" and "passive navigation", respectively. The analysis of the sketch maps indicates indeed that passive navigation led participants to encode route-based representation of the map segments. Participants in the active navigation condition were comparatively more inclined towards a survey representation. Yet, there was no correlation between map sketch representation and tour-integration performance that would indicate that the differences in tour-integration performance reported in Experiments 4-5 were based on simplified route representations in the passive navigation condition.

Interestingly, navigation condition did not affect tour-integration performance, but spatial indication. Apparently, without actual exposure to the environment, the outlines of all paths given in the tour-integration task enabled participants both in the active and in the passive navigation condition to perform well in this task (but as hypothesized, tour-integration performance after studying maps in the lab setting was on average worse than after studying maps in the environment as in Experiments 4-5). The specific locations that had to be recalled in the spatial indication task required a better integration of the map segments into the whole map. This may indicate that this task is more sensitive to our manipulation of navigation control and would have been the more suitable task to detect spatial learning effects in the previous experiments. However, the significant correlation between the spatial indication task and the sketch maps also showed that this measure are confounded by differences in the mental representation of the environment than the tour-integration task, a confound we urgently tried to avoid.

Environment knowledge showed little, if any, effects. In other words, participants were not able to apply previous real experiences with the environment to a tour learned in a laboratory setting. The somewhat better tour-integration performance of naïve participants over participants familiar with the environment implies that some environment knowledge rather confused participants than supported their recall of the tour.

3.5 Discussion of Series 2

We tested the development of different levels of spatial knowledge after driving or co-driving a tandem bike in a real large-scale environment under active and passive navigation control: Actively deciding about a course should be equally or more relevant for memorizing spatial information than the execution of this decision (i.e., driving). Two experiments with participants naïve (Experiment 4) and familiar with the environment (Experiment 5) confirmed this assumption: The ability to develop a mental representation of the whole tour and environment from fragmented maps, measured with a tour-integration task, was improved by active navigation, but not by movement control, if the environment was unfamiliar (Experiment 4). Given previous knowledge about the environment (Experiment 5), participants showed a worse mental representation of the park environment only when they neither were required to decide actively about the course to be taken, nor had controlled movement (i.e., being co-drivers). Thus, controlling movement enabled driving participants to compensate for the disadvantages of passive navigation.

An additional laboratory study (Experiment 6) confirmed that we successfully manipulated active navigation, although participants in the passive navigation condition tended to simplify the map segments into a route-based representation more than participants in the active navigation condition: there were no hints that the effects in Experiment 4-5 can be explained with different mental representations of the map segments. Experiment 6 also suggests that the effects of active navigation are stronger if studying the maps is followed by an actual navigation decision as in Experiment 4-5.

Unfortunately, a free orientation task turned out to be difficult to realize in the present setting. There were no differences in free orientation performance between the experimental conditions in Experiment 4. A planned task in Experiment 5 was dropped after a fifth of the participants showed no variance in their route choice at all. Reasons that contributed to these null findings are first, the rather open-spaced environment that made general orientation by sight easy, and second, the availability of a complete map in the tour-integration task prior to the free orientation task. (However, a reversed task order would have resulted in a second exposure to the environment, confounding the interpretation of all other tasks.) Thus, it can be argued that the research at hands misses immediate evidence that our conclusions are ecologically valid. However, Experiment 6 demonstrated the validity of the tour-integration task as a measure of survey knowledge with substantial correlations with a map drawing task and a spatial indication task. Additional evidence comes from Experiment 3, which included both tour-integration and free orientation. In Experiment 3, active navigation enabled superior tour-integration performance of participants who observed movement. More importantly, whereas free orientation performance of participants who controlled movement was superior after passive navigation, active navigation enabled participants who observed movement to show comparable free orientation performance. Thus, active navigation control did not only benefit co-drivers' mental representation of the environment, but also their ability to apply this representation to an actual navigational task in a experimental setting very similar to that in the study at hand. For these reasons, we think that our interpretation is ecologically valid.

Given the rather inconsistent findings in active navigation research regarding landmark knowledge (see Wallet et al., 2008, for an overview), we had no clear hypotheses about the effects of our manipulations on landmark recognition. Indeed, the obtained results are somewhat conflicting on the first glance. In Experiment 4, active navigation deflected both drivers and co-drivers from perceiving and remembering landmarks, resulting in worse landmark recognition compared to participants in the passive navigation condition. There was no effect of movement control. In Experiment 5, with more familiar participants, drivers showed better landmark recognition than co-drivers, but there was no effect of navigation control. A descriptive analysis of one third of the participants who rated their familiarity with the environment lowest in Experiment 5 supports the assumption that the higher level of environment knowledge in Experiment 5 elicited this difference: the data pattern of unfamiliar participants resembled the pattern of Experiment 4, with more distinct differences between the navigation conditions than between the movement control conditions. But how can we explain the advantage of familiar drivers as compared to co-drivers in landmark recognition? We hypothesize that sitting on the front seat and controlling movement may have included additional demands on cognitive resources such as identifying the next crossing and other obstacles. Drivers who already knew the environment may have been less strained by these demands than drivers without environment knowledge, and were therefore more able to encode information on the environment. In other words, a driver perceiving a landmark at a specific turn may display an example of interactive context encoding (Baddeley, 1982), where the landmark-object becomes part of the specific action of maneuvering only if they are somewhat familiar with the environment and thus not overstrained by task demands.

Using map segments for navigation may have biased participants towards a survey-based representation of the environment and distracted them from relying on landmark information (Fields & Shelton, 2006; Rossano & Reardon, 1999; Shelton & McNamara, 2004; Taylor et al., 1999). Additionally, the landmarks selected in our experiments were unique in appearance and evenly distributed over the environment, but potentially too arbitrary in their connection to the route to provide relevant navigation information. Hence, it is possible that participants did not take landmarks as dominant references for turning points while navigating with map-segments. From an empirical point of view, it would be a challenging attempt to transfer active and passive navigation conditions to a more route knowledge-centered setting and it is an interesting question whether such an attempt would lead to similar patterns in landmark recognition and ordering tasks as we found in the tour-integration task (see Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Foo et al., 2005; Reagan & Baldwin, 2006, for similar attempts).

3.5.1 Connections with Action Memory Research

According to our findings, there are only few memory-performance differences between drivers and co-drivers. This is in line with the predictions of active navigation research, but it contrasts intuitive assumptions. Related research areas that focus on similar comparisons of different study conditions and their effects on memory performance support our findings. For example, bio-psychological research has shown that neurophysiological activity may be comparable after enactment and observation of actions (Rizzolatti, Fogassi, & Gallese, 2001). Similar evidence comes from research on action memory (see section 1.1): newer accounts stress the idea that information processing during enactment is tied by the task demands of enactment (e.g., Steffens et al., 2003), and that the crucial mechanism provoking the enactment effect is semantic elaboration of the study materials (e.g., Knopf et al., 2005; Kormi-Nouri, 1995; Steffens et al., 2007). Indeed, recall performance after observation is often comparable to that after enactment (e.g., Engelkamp & Dehn, 2000; Helstrup, 2005; Steffens, 2007). Thus, recent frameworks of action memory parallel route-learning research in emphasizing the role of active elaboration of the to-be-studied materials. Our findings that co-driving (or observation) is not inferior to driving (or enactment) for encoding information if active elaboration is assured are in line with this.

Action memory research also helps to interpret the superior landmark recognition but comparable landmark ordering performance of drivers compared to co-drivers in Experiment 5: Studies on action memory suggest that enactment (i.e., driving) especially benefits recognition, whereas relational information such as the temporal order of actions (or landmarks, respectively) can be equally or better processed after observation (i.e., co-driving, Engelkamp & Dehn, 2000). Future research may try to use free recall tasks rather than recognition tasks to address potential differences in the development of landmark and route knowledge of drivers and co-drivers: free recall performance in action memory has been considered as a function of relational information of items (comparable to route knowledge) in addition to processes also relevant for recognition (comparable to landmark knowledge, i.e., McDaniel & Bugg, 2008). Thus, free recall tasks may be less biased towards drivers or co-drivers than traditional landmark recognition and landmark ordering tasks.

3.5.2 Conclusion

To conclude, Experiment 4-6 successfully transferred the experimental setting of the first series of experiments (especially of Experiment 3) to a real-environment and confirms the validity of findings from virtual environments. Chapter 3 showed that driving may in some cases lead to better landmark knowledge, but not better route knowledge than co-driving a tandem. More importantly, active decision-making enabled both co-drivers and drivers to develop a good mental representation of the tour from fragmented maps, whereas active movement control only compensated for passive navigation when the environment was already familiar. Participants who lacked active involvement in both maneuvering as well as navigation showed an inferior mental representation of the tour. Thus, we found no evidence for the assumption that one needs to drive in order to remember a new route: Active navigation is even more relevant as a learning strategy than maneuvering the vehicle.

4. Discussion

This chapter aims to integrate the findings of Chapter 2 and Chapter 3, followed by a detailed analysis of the limitations of both series of experiments. Subsequently, additional implications of action memory research for active navigation are outlined and a final conclusion is provided.

4.1 Overview

Two series of experiments dealt with the question whether driving a vehicle is genuinely advantageous over co-driving this vehicle, or whether such an advantage depends on factors that are frequently, but not necessarily entangled with driving. Series 1 used virtual environments to contrast movement control against learning intention (Experiment 1), instruction control and instruction specificity (Experiment 2), and decision control (Experiment 3) in counterbalanced designs. Series 2 extended this approach to a real world setting. In two subsequent studies people were positioned on the front or the back position of a tandem bike, and provided with differently elaborated maps (Experiment 4-5, using a experimental design closely related to Experiment 3). An additional study addressed potential limitations in a lab setting (Experiment 6).

Generally, both series support the postulate that active movement control is indeed not inherently advantageous over observed movement in spatial learning, but this conclusion depends on the level of spatial knowledge. Specifically, the development of landmark and route knowledge may be genuinely benefitted by movement control: Self-contained movement enabled consistently better landmark knowledge throughout Series 1, and this advantage was not affected by any of the other manipulations. In Series 2, landmark knowledge of drivers was superior to that of co-drivers when the environment was familiar (Experiment 5), but not when the environment was unfamiliar (Experiment 4). Several factors may have contributed to the advantage of participants who controlled movement in both series of experiments, with the most important aspects being discussed in section 2.5 and 3.5, and additional thoughts provided in the following sections. However, all potential confounds that could account for the landmark knowledge advantage of drivers apply for specific settings or specific experiments only (e.g., the explicit mentioning of all landmarks in the instructions of Experiment 1-2, or existing familiarity with the landmarks in Experiment 5). Thus, there is no general confound that would explain the drivers' recognition advantage.

Considering that the research at hand includes a broad range of experimental settings and manipulations, it appears fairly safe to assume that driving a vehicle (or controlling movement in a virtual environment, respectively) provides a genuine advantage in landmark knowledge.

This conclusion displays a contradiction to the hypothesis of this research on the one hand. On the other hand, it can be argued that this finding, although of theoretical interest, does have rather minor consequences for actual route learning: remembering landmarks appears less important to optimize one's route choice, or to identify the encountered route on a map.

This reasoning is supported by the findings on survey knowledge. More specifically, in contrast to landmark knowledge, the development of survey knowledge depends on a mandatory elaboration of spatial information. This elaboration is in many cases guaranteed by driving and self-contained movement, respectively: In Series 1, self-contained movement enabled consistently good way-finding performance in all experiments, and also advantages in the mental representation of the environment in combination with instruction control (as indicated by the tour-integration task in Experiment 2). In Series 2, driving compensated for passive navigation when the environment was familiar (Experiment 5). However, the elaboration of spatial information is not inherently linked to driving and self-contained movement. If a sufficient level of elaboration can be assured for co-drivers and observers, respectively, their survey knowledge is not inferior to that of drivers.

The term "mandatory" needs to be stressed in this context: It was reasoned in Experiment 1 that the intention to learn a specific route might enable participants who observe movement to compensate potential disadvantages. Yet, learning intention showed little effect at all: the intention to memorize a route appears insufficient to enforce the necessary elaboration of spatial information. The best method to assure the mandatory elaboration of spatial information for co-drivers was active involvement in the decision about the correct route, in both virtual and real environments: In Experiment 3, active navigation control enabled superior tour-integration performance of participants who observed movement, and also comparable way-finding performance (which had been consistently inferior to self-contained movement in Experiment 1-2). In a real environment, co-drivers performed consistently well in the tour-integration task when they were required to decide actively about the route (Experiment 4-5).

Taken together, the experiments support the initial hypotheses. Controlling movement in virtual environments provided no general advantages in spatial learning as compared to the observation of this movement. Depending on the available information and encoding strategies, controlling movement can even be disadvantaged to observing movement. The ecological validity of this finding was confirmed in a real environment setting: Active participation in navigation was more important for route learning than driving a vehicle.

4.2 Issues of Series 1

Definitions and conceptualizations of active navigation vary in the existing literature, as has been discussed in section 3.1.1. Consequently, Series 1 aimed to disentangle the inconsistencies of active navigation research and to identify factors central to active navigation. It succeeded in that endeavor for the factors movement control, decision control, instruction control, instruction specificity, and learning intention, and confirmed the assumption of decision role as a central factor in active navigation. The present approach extends previous findings that did not use completely counterbalanced experimental designs (Farrell et al., 2003), or have been limited by the choice of applied spatial tests (Wilson et al., 1997). However, this attempt also has some limitations, which are discussed below.

4.2.1 Gender and Computer Game Experience

Potential confounds result from the tested sample in this series of experiments. Whereas an equal number of women and men participated in Experiment 1, a strong majority of women were included in Experiment 2-3. Gender was not taken into account as a independent factor, although there is some evidence for gender differences in spatial cognition (e.g., Bosco, Longoni, & Vecchi, 2004; Cutmore et al., 2000; De Beni, Pazzaglia, & Gardini, 2006).

The gender distribution may also amplify a bias towards a computer game-novice group, as computer gaming is more common among men than women (Griffiths, Davies, & Chappell, 2004). It seems likely that computer game experience affects the ability to develop a mental map of virtual environments. Computer game experience was assessed in all three experiments. If significant correlations with any of the dependent variables appeared, this confound was subsequently controlled as a covariate. However, computer game experience was on average low to modest, ranging from $M = 1.19$, $SD = 0.92$ (Experiment 2) to $M = 2.54$, $SD = 1.43$ (Experiment 1) on a 5-point scale. Thus, most of the participants were not used to move in virtual environments or to memorize their spatial properties. Considering that expert gamers develop superior spatial abilities in computer games as compared to novice players (Greenfield, Brannon, & Lohr, 1994; Sims & Mayer, 2002), it is possible that testing a sample of high experienced computer gamers might alter some of the reported findings. For example, if the null-effects in pointing and path sketching result from the novelty of virtual environments (see section 2.2.2.3), a greater experience with virtual environments may significantly decrease error variance and reveal interpretable data in these tasks on the one hand. On the other hand, experienced gamers may experience fewer problems in way finding even after observed movement, thus threatening the interpretability of this task.

Taken together, people are likely to be generally familiar with the mode of transportation in a driver/co-driver situation (e.g., a car or a tandem bike), and they are also used to the spatial properties of the physical word. This did not apply for the majority of participants in regard to the virtual environments used in Series 1. Although testing participants with little skills may have some advantages (e.g., maximizing the effects of experimental manipulations), there are several reasons (e.g., increased abilities to encode spatial information in virtual environments, closer resemblance to real-life situations) that suggest the inclusion of experienced computer gamers.

4.2.2 Environment Issues

Several issues can be raised about the specificities of the environments, for example route complexity. Wilson and colleagues (1997) already discussed potential effects of environment complexity. However, both environments used in their study were fairly simple (five separated areas in Experiment 1, one area containing a number of random walls in Experiment 2). The study of Wallet and colleagues (2008) compared spatial learning of a simple and a complex route and showed that active navigation exceeded passive navigation in way-finding tasks in disregard of route complexity, but that sketch-drawing of complex routes was significantly improved by active navigation. Accordingly, rather complex environments were created in Series 1. However, there were neither pretests nor ratings in the actual experiments that would provide information how complex participants perceived the environments to be. Obviously, the chosen complexity of the environments was sufficient to avoid floor or ceiling effects for the most part. Nevertheless, pretesting different levels of complexity would have been appropriate.

The virtual environments used in this series of experiments were multiple times more detailed as compared to studies on active navigation that were conducted in the last millennium due to technological developments. Experiment 1 in particular consisted of a detailed, open, urban environment with streets, buildings, and greens. The environment also included a large number of corresponding landmarks. However, this environment did not serve a purpose beyond the experiment. This limitation applies even more to Experiment 2-3, where closed mazes with a limited number of random landmarks were used. It is uncertain to which extend this artificialness might have affected the findings in Series 1.

For example, the environments used Experiment 2-3 differ from real environments (with a potentially countless number of possibly relevant landmarks) in regard to the implementation of random objects as landmarks, which were the only objects in the environments as well. Thus, these experiments fall short to provide further insight whether the experimental conditions differ in the ability to identify landmarks that are meaningful for navigation.

Experiment 1 did provide evidence that there are differences in the ability to identify meaningful landmarks: participants in the self-contained movement condition showed particularly good recognition of landmarks that indicated turns (and were of higher relevance for navigation). Thus, it was reasoned that a focus on relevant landmarks only was sufficient to analyze the encoding of landmark knowledge. However, the implementation of a limited number of landmarks resulted in a methodological flaw of Experiment 2-3: There were landmarks on the intended route only, but not on detours and dead ends. Thus, the way-finding task could be solved well by moving from one landmark to the next rather than by accessing a mental map of the environment. This explains why participants in the no-navigation condition in Experiment 3 showed very good performance in the way-finding task (see Table 3): they were more likely to realize the link of landmarks because they were not focused on studying the fragmented maps.

Thus, the ecological validity of these experiments could have been improved by implementing more landmarks. It is unlikely but possible that other environmental features that are inherent elements of real environments and route learning were missing in the virtual environments used in this series of experiments, which may consequently limit the generalizability of the findings at hand.

4.2.3 Self-Contained and Observed Movement as an Instance of a Driver/Co-Driver Situation

Self-contained movement was executed by pressing four keys, with the addition of head rotation via mouse movement in Experiment 1. The complexity of the necessary actions to control movement appears trivial compared to maneuvering a car (or a tandem bike). Thus, the present manipulation of movement control as a valid conceptualization of a driver/co-driver situation can be questioned: the amount of cognitive resources required of a participants in the self-contained movement condition relative to someone driving a real car is unclear. The present scenario may overestimate spatial learning after self-contained movement due to little cognitive constraints, because the rather simple control mechanism and a virtual environment do not impose additional difficulties (e.g., traffic) as compared to driving vehicle in a real environment. It is not clear whether the available resources may have affect spatial learning. Future studies could include additional measures of attention and effort ratings as well as manipulations of the difficulty of maneuvering. If drivers need to spend more attention to the maneuvering itself, this may have negative effects on their spatial learning.

In contrast, participants who observed movement may have been more constrained as compared to a real co-driver situation in regard to their field of vision (also see section 2.5). Thus, the present scenario may inhibit the processing of spatial information (e.g., landmark knowledge) via observed movement. This issue could be addressed in a "piggyback" design as follows: conditions for participants who control movement on one computer are the same as in the present experiments, while observing participants sit in front of a second, linked computer that shows the movement of their partners' avatar in the environment from third-person "over-the-shoulder" perspective. They have no control on the general movement, but they can control their field vision with the mouse. This design would allow to disentangle movement control from vision control. If the difference in landmark knowledge stems from a limited field of vision, this approach should decrease the landmark knowledge disadvantage after observed movement.

4.2.4 Route Learning versus Free Exploration

Another factor that deserves further discussions concerns the antagonism of free exploration and route learning that has already been mentioned in section 2.5. Although the ecological validity displays a strong arguments pro route learning and contra free exploration of an environment, it can be argued that there are good reasons to analyze active navigation in more ambiguous settings and less focused on a specific tour: such a setting resembles more closely to a person's exploration of a foreign city or a large park without an intention to memorize spatial properties in mind. However, spatial properties still need to be recalled in order to assure the correct identification of a return tour. Additionally, studies that used a free exploration scenario appear more likely to find no differences between active and passive navigation conditions (Wilson, 1999; Wilson et al., 1997). Thus, a systematic comparison of a free exploration condition with a route-learning condition could have clarified the potential impact of this factor, which may have contributed to the inconsistencies in active navigation research. However, a comparison of these tasks appears difficult to achieve while holding exposure to the environment constant in other regards.

It can be argued that the free exploration of an environment displays a maximum of decision control. The converse argument implies that the implementation of decision control in Experiment 3-5 (although unobtrusively limited to a intended route) bears some resemblance to the free exploration of an environment. A transfer of the outlined conclusions for route learning on a situation more related to a free exploration of an environment appears therefore justified.

4.3 Issues of Series 2

Considering that there is quite some research on spatial learning of drivers (e.g., on the effects of route guidance systems, see Krüger et al., 2004; Lee & Cheng, 2008), differences in spatial learning of drivers and co-drivers have attracted surprisingly little research. This may be partly explained by the frequently mentioned believe that driving is essential to memorize routes: Similar to the believe that “learning by doing” is the best way of learning an activity as compared to other study conditions as for example “learning by viewing”, the lay acceptance of this assumption might have limited research efforts. Some studies on spatial cognition in real environments alluded to this topic, but were not primarily concerned with active navigation (Münzer et al., 2006; Willis et al., 2009, see section 3.1.1). Thus, Series 2 is one of the first attempts to manipulate active navigation in a real environment. Comparing spatial knowledge that people acquired on the front seat or the back seat of a tandem-bike as an instance of a driver/co-driver situation proved to be a fruitful approach that yielded insightful results.

However, Series 2 also has some limitations, partly due to the available resources. For example, the acquisition of participants proofed to be substantially more extensive than in laboratory settings. For this reason, every participant was involved in navigation in the design of Experiment 4-5 (i.e., maps were used in the active and in the passive navigation condition, and there was no control condition without a map). This was necessary because showing maps to some participants and no maps to others may elicit substantial differences in the mental representations of an environment (e.g., Münzer et al., 2006; Willis et al., 2009), which would have confounded the experimental manipulations. (Even with the minor differences between the active and passive versions of the map fragments, Experiment 6 showed that this was already enough to result in some differences in the mental representations of the maps.) A condition of drivers and co-drivers who did not see maps at all (comparable to Experiment 3) would have been very informative in regard to baseline performances in landmark recognition, tour-integration, and free orientation. Such a control group could have replicated and supported the landmark recognition advantage of the no-map condition as compared to both map conditions (see Table 3). Additionally, it was speculated that the increased focused on landmarks was responsible for the very good way finding performance of participants in the no-navigation condition (see section 2.4.3). A control group without maps in real environments as in Experiment 4-5 would could have clarified whether the effect in Experiment 3 represents a confounds due to the very limited number of landmarks in this experiment, or whether there is general, strong effect of good landmark knowledge on free orientation performance.

The representativeness of the participant sample could have been improved in some regards: First, the issue of potential gender effects in spatial learning has already been raised in section 4.2.1. Experiment 4-6 included a large majority of women. The data of all dependent variables were checked but revealed no gender effects. However, the distribution is too askew to draw valid conclusions on potential gender effects. Second, Experiment 4-5 tested participants with different levels of environment familiarity. Participants in Experiment 4 were completely unfamiliar with the environment for the most part. In contrast, environment familiarity was rather modest than generally high in Experiment 5, with participants ranging between being completely unfamiliar to highly familiar with the park. An exclusion of participants unfamiliar with the environment would have been appropriate to strengthen the discriminatory power between the experiments for environment familiarity.

The considerations regarding gender distribution and environment familiarity do not impose a large threat to the validity of the findings, but a higher generalizability of the results and additional insights in spatial learning would have been possible by a more careful selection of participants. However, practical expenses of time and resources limited the feasibility of conducting a larger and more selective sample.

4.3.1 Tandem Cycling as an Instance of a Driver/Co-Driver Situation

It is quite safe to say that driver/co-driver situations appear for the most part when driving a car. Thus, the most valid scenario for the present research would have been accomplished with a car. However, this approach appeared inapplicable due to a large number of individual (e.g., driving experience) and situational (e.g., traffic density) confounds.

Although using a tandem bike to simulate a driver/co-drivers situation brought about several advantages, this choice may also have had effects of its own right on spatial learning. First, the speed of travelling with a tandem bike is significantly higher than the speed of a pedestrian, but much slower than a car. A passed landmark is more likely to be missed with increasing speed. Second, higher speed also enables to travel larger distances, resulting in exponentially increasing number of potentially significant landmarks and turns, thus requiring adaptive and therefore more elaborate strategies than simple orientation by sight.

This reasoning finds support by a preliminary experiment that was conducted in the course of this dissertation and used a wheelchair for means of transportation. In this experiment, one “co-driving” participant sat in the wheelchair and was pushed by a second, “driving” participant. Navigation was manipulated by providing map-segments to one person and no map to the other, comparable to the active navigation condition and the no navigation condition in Experiment 3. Sitting in the wheelchair (as an instance of co-driving) enabled superior landmark recognition, especially when the participants did not need to study maps, thus contrasting the findings of the present research. The same participants also showed very good performance in a free orientation task. This can be interpreted as a result of the additional cognitive resources available to this experimental condition to develop a representation of the environment as compared to the other conditions, which were occupied by maneuvering or navigation. Thus, speed and travelled distance can be potential factors that affect spatial learning and cognitive strategies differently under different learning conditions.

One may argue that a driver/co-driver situation on a tandem bike differs from driving a car in so far as co-drivers are physically involved in pedaling and leaning into turns. Thus, it is possible that the physical involvement enabled interactive context encoding of co-drivers (Baddeley, 1982, also see section 3.5), which consequently overshadowed stronger advantages of drivers over co-drivers. Consequently, co-drivers should show inferior spatial learning in a setting that does not require them to be physically active. However, this reasoning is invalidated by findings, which demonstrate that action memory is not determined by motor code (e.g., Knopf et al., 2005). Additionally, the conceptualization of self-contained versus observed movement in Experiment 1-3 displays a situation with a physically inactive co-driver; still, spatial learning did not depend on movement control alone.

Future studies may try to extend these findings with different approaches. Driving simulators would combine the advantages of virtual environments with a high approximation to real driving, but are limited in their ecological validity due to the artificialness of the virtual environments (see also section 4.2.3). The implementation of a wheelchair displays some potential in this regard, which may be constricted by the range and speed of this vehicle. Alternatively, golf carts that need to be maneuvered on a golf course would combine a clear distinction of physical activity between drivers and co-drivers with a large-scale environment that consists of an inherent spatial structure.

4.4 Further Implications of Action Memory Research

Potential connections of action memory research with active navigation have been introduced in section 1.1 and discussed in section 3.5.1. However, additional implications regarding route knowledge can be drawn from this connection.

Experiment 5 showed superior landmark recognition (a finding supported by Series 1) but comparable landmark ordering performance of drivers compared to co-drivers. This finding matches action memory research, where an enactment effect depends on the applied memory task. Whereas the majority of studies comparing enactment and observation found no differences in free recall tasks, there is a robust advantage of enactment over observation in recognition tasks. The interpretation of this finding is that recognition tasks are more sensitive to detect differences in the encoding of item-specific information (i.e., the properties of specific verb-object combination as used in most studies on action memory). In contrast, free recall performance in action memory has been considered as a function of encoding item-specific and relational information (i.e., McDaniel & Bugg, 2008). Relational information regards for example the temporal order of single action phrases. Indeed, there is some evidence that the observation of actions benefits the processing of these relational information (Engelkamp & Dehn, 2000; Steffens, 2007).

Applied to a driver/co-driver situation, this suggests that the drivers' advantage in landmark recognition tasks displays a better encoding of item-specific landmark information. However, it can be questioned whether a superior encoding of item-specific information provides an advantage in every-day-life situations. Although a good recognition of specific landmarks appears desirable, it does not guarantee successful navigation: in contrast to recognition tasks in laboratory settings, missing one landmark and leaving the intended route means that further landmarks fail to appear. Thus, noticing the absence of recognizable landmarks provides evidence for the preceding failure. This ability takes form in the recall of a landmark one expects to appear, which emphasizes the importance of free recall of landmarks and relational information in navigation as compared to recognition of landmarks.

Transferring the finding that observation of actions enables superior encoding of relational information on active navigation research suggests that co-drivers should show superior route knowledge as compared to drivers. In the research at hand, only Experiment 5 contained an appropriate route knowledge test. The landmark-ordering task in this experiment indicated no difference between drivers' and co-drivers' performance, and thus contrasts the preceding reasoning. However, participants did not need to recall the landmarks in this task, but were required to order all landmarks presented to them. This approach may have overshadowed effects of relational encoding by co-drivers. Additionally, the experimental setting primed participants' towards a map-based rather than a landmark-based representation of the environment, and the tested landmarks may not have been the landmarks participants would have recalled in a respective free recall task (see also section 3.5).

Thus, the empirical evidence against better encoding of route knowledge by co-drivers is limited to the data of one experiment, and biased for the mentioned reasons. Action memory research suggests that future research should include free recall tasks and recall order tasks in addition to recognition tasks to analyze the development of landmark knowledge of drivers and co-drivers.

4.5 What Defines "Active Navigation"?

The present research outlined that active navigation consists of numerous factors. This rises the question what the term "active navigation" actually refers to. In line with the reasoning of previous studies (Farrell et al., 2003; Wilson et al., 1997), the findings at hand suggests that decision control could be considered as the most central aspect in active navigation. In this case, active navigation would equal decision-making. However, although this research underlines decision control as a central element of active navigation, these concepts cannot be considered as exchangeable. Movement control demonstrated to be more central than decision making for landmark knowledge (Experiment 1-3, 5), and instruction control enabled a survey knowledge advantage of participants who movement control (Experiment 2).

It is concluded from the present findings that (at least in regard to survey knowledge) participation in the navigation process must cross a certain threshold to ensure encoding of spatial information. However, the exact mechanisms that trigger this crucial participation remain obscure. Thus, the concept of active navigation in its current use remains too unspecific to allow for general predictions on spatial learning.

Future research may try to implement measures of mental effort or secondary tasks during the study phase to determine a participant’s involvement in the navigational task. This may provide further insight which conditions determine active navigation. However, the fuzziness of active navigation does not limit the central conclusion of the research at hand: Spatial learning of co-drivers can be as good as that of drivers.

5. Conclusion

This research aimed to clarify whether movement control (i.e., driving a vehicle) leads to genuinely better spatial learning than the observation of this movement (i.e., co-driving).

It contributes to solving existing discrepancies in active navigation research by contrasting movement control in counterbalanced designs with other factors that are relevant for spatial learning. Furthermore, this research displays a significant advancement of previous studies on active navigation that were almost exclusively limited to virtual environments: It is one of the first studies that manipulates active navigation in a real-world setting and demonstrates the general ecological validity of active navigation research in virtual environments for spatial cognition in real environments.

The data suggest that controlling movement as a driver may indeed provide a genuine advantage in the development of landmark knowledge. However, the present findings show that the development of survey knowledge is for the most part not determined by active movement control per se, but rather by a mandatory participation in the navigational process. Controlling movement of a vehicle does frequently, but not exclusively, guarantee this participation. Given a situation that forces a co-driver to the necessary elaboration of spatial information (e.g., by navigation control), there is no disadvantage as compared to a driver in the development of survey knowledge.

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Summary

The research at hand aims to clarify whether movement control (i.e., driving a vehicle) leads to genuinely better spatial learning than the observation of this movement (i.e., co-driving), or whether such an advantage depends on factors that are frequently, but not necessarily entangled with controlling movement of a vehicle: For example, research on active navigation suggests that the execution of movement could be less important than the decision where to move. Thus, a navigating co-driver may not be disadvantaged as compared to a driver who follows navigational instructions. Two series of experiments were conducted to test the hypothesis that spatial learning depends on an active encoding of the spatial information, but that controlling movement does not provide general and inherent advantages in spatial learning as compared to observing this moving.

The theoretical underpinnings of this thesis originate in research on action memory, a research field that deals with the comparison of different study conditions: Classic frameworks of action memory research postulated that enactment (as an instance of driving) provides optimal encoding conditions, resulting in superior memorization of actions and activities as compared to verbal learning or observation (as an instance of co-driving). A prominent theory reasoned that the so-called enactment effect originates in the additional motor code provided by the execution of an action. However, whereas there is a robust enactment effect as compared to verbal learning, recall performance after observation is often comparable to enactment. Indeed, recent accounts in action memory theory put more stress on the role of active elaboration of the to-be-studied materials. Transferred to route learning, this implies that spatial learning of drivers and co-drivers could be comparable if active elaboration of spatial information is assured. An equivalent comparison of study conditions in spatial cognition research has been labeled active navigation. Active navigation research emphasizes the idea that self-contained and free navigation benefits spatial learning as compared to a more passive, observing mode of navigation, and has been almost exclusively studied in virtual environments. However, there are numerous studies in support as well as in contradiction to the idea of an active navigation advantage. Several authors already discussed varying definitions and conceptualizations of active navigation as sources of these inconsistencies.

Series 1 aimed to identify and disentangle factors crucial in active navigation research by using virtual environments (N = 275). Emanating from a driver/co-driver situation, the central distinction concerned movement control (i.e., self-contained vs. observed movement). This differentiation is also reflected in most studies of active navigation. Thus, movement control was manipulated as a first factor, and contrasted to one of three factors that have been discussed in active navigation research. Experiment 1 concerned the role of learning intention, which has been discussed as a potential confound in active navigation research by some authors. Given that the majority of experiments are conducted in laboratory settings, participants are likely to expect some kind of testing. Thus, it is possible that the resulting learning intention overshadows eventual effects of movement control. Experiment 2 concerned potential effects of instruction specificity and instruction control. Regarding instruction control, it appeared plausible that (active) reading of instructions could provide better encoding of spatial information than (passive) listening to these instructions. Findings on goal specificity imply that even small differences in the navigational instructions may affect spatial learning. Thus, instruction specificity was manipulated by providing verbal instructions that included landmark information only or additional survey information. If drivers read the instructions, and these instructions furthermore emphasize a specific level of information (e.g., survey information), they may therefore show better survey knowledge. Thus, such an advantage could represent a result of instruction control and instruction specificity rather than of movement control. Experiment 3 extended this approach to map-based instructions that included an element of decision-making. Some studies emphasize that decision control could be more important in active navigation than movement control (i.e., a co-driver may be assigned to the navigator role, thus controlling decision and consequently showing better spatial learning than the driver). Thus, participants received fragmented maps where the optimal route had to be identified in an active navigation condition, or where the optimal route was indicated in a passive navigation condition. A no-navigation condition received no maps.

In all three experiments, landmark knowledge (as indicated by a recognition task) was consistently better after self-contained as compared to observed movement, and little affected by the other manipulations. The development of survey knowledge (as indicated by a way-finding task and a tour-integration task, where the participants' mental representation of the environment was tested by requiring them to outline the route into a schematic map) was substantially affected by factors in addition to movement control. The findings of Experiment

3 imply that active decision control is more central than active movement control. In Experiment 2, an advantage of self-contained over observed movement required instruction control, further enhanced by additional survey information in the instructions. If the instructions were received via listening, there was no advantage of self-contained over observed movement. In contrast to the hypothesis, intentional learning in Experiment 1 did not provide advantages over an incidental learning condition and showed no effects on the manipulation of movement control. In conclusion, the findings of Series 1 are consistent with the idea that movement control is a central factor in active navigation with regard to landmark knowledge but that there is no genuine advantage of self-contained over observed movement regarding the development of survey knowledge, which depends on the active elaboration of spatial information.

Series 2 applied these findings in a real environment context. Most research in the field of active navigation has been conducted in virtual environments, or concerned the transfer of spatial knowledge from virtual to real environments. Some studies in real environments that alluded to active navigation were more focused on effects of different instruction modalities than on active navigation as discussed further above. Thus, Series 2 is one of the first to manipulate central factors in active navigation in a real world setting (N = 232). Corresponding to Experiment 3, the effects of movement control and decision control on spatial learning were addressed: Participants were seated on the front or back position of a tandem bike and received differently elaborated map segments for navigation in a park environment.

The results are predominantly in line with the findings of the first series. Driving did enable genuinely better landmark knowledge than co-driving, but only for participants who were familiar with the environment. Navigation control was more important than movement control for the development of survey knowledge. Tour-integration performance was benefitted by active navigation control, but not by movement control if the environment was unfamiliar (Experiment 4). Driving helped participants more familiar with the environment to compensate for passive navigation (Experiment 5). Way-finding tasks failed to produce analyzable data due a combination of experimental procedure effects and environmental limitations, thus presenting a threat to the ecological validity of the study. Experiment 6 validated the tour-integration task as a measure of survey knowledge to account for this shortcoming. Additional support comes from Experiment 3, which demonstrated that active decision-making benefitted not only tour-integration but also way-finding performance of participants who observed movement. Series 2 implies that active navigation control can be more important than driving for route learning in real environments. This is clear for unfamiliar environments, whereas driving a vehicle enables to compensate for active navigation control in a more familiar environment.

In conclusion, this research found that spatial learning in active navigation research is for the most part not determined by active movement control per se (i.e., driving a vehicle), but rather by a mandatory participation in the navigational process. Given a situation that forces a co-driver to do the necessary elaboration of spatial information, there is no disadvantage in survey knowledge. However, the data suggest that controlling movement as a driver may provide a genuine advantage in the development of landmark knowledge. The present findings contribute to solving existing discrepancies in active navigation research by contrasting movement control in counterbalanced designs against a number of factors relevant for spatial learning. Furthermore, the findings demonstrate the general ecological validity of active navigation research in virtual environments for spatial cognition in real environments with one of the first approaches to manipulate active navigation in a real-world setting.

Zusammenfassung

Die vorliegende Arbeit zielt auf die Klärung der Frage ab, ob aktive Kontrolle über die eigene Bewegung (beispielsweise beim Fahren eines Fahrzeugs) zu inhärent besserem räumlichen Lernen führt als die Beobachtung dieser Bewegung (beispielsweise in der Rolle eines Beifahrers), oder ob solch ein Vorteil von anderen Faktoren abhängt, die häufig, aber nicht zwangsläufig mit der Steuerung eines Fahrzeugs verbunden sind: Bestehende Forschungsergebnisse zu aktiver Navigation legen beispielsweise den Schluss nahe, dass die eigentliche Ausführung der Bewegung für das räumliche Gedächtnis weniger entscheidend sein könnte als die aktive Entscheidung über die Bewegungsrichtung. Demzufolge wäre ein aktiv navigierender Beifahrer gegenüber einem Navigationsanweisungen befolgenden Fahrer nicht zwangsläufig benachteiligt. Diese Argumentation kann auf eine vorhandene Lernintention oder die Instruktionskontrolle übertragen werden. Diese Hypothese wurde mit zwei Experimentserien untersucht.

Die theoretischen Wurzeln der vorliegenden Dissertation liegen im Bereich der Handlungsgedächtnisforschung, die unterschiedliche Lernbedingungen miteinander vergleicht. Klassische Modelle der Handlungsgedächtnisforschung postulieren, dass die Ausführung einer Handlung (vergleichbar mit der Rolle eines Fahrers) die optimale Lernbedingung darstellt, welche die Speicherung von Handlungen und Aktivitäten besser ermöglicht als verbales Lernen oder die Beobachtung von Handlungen (vergleichbar mit der Rolle eines Beifahrers). Eine weitverbreitete Theorie begründet diesen sogenannten Handlungseffekt mit der zusätzlichen motorischen Information, die mit der Ausführung einer Handlung einhergeht. Während es jedoch einen stabilen Handlungseffekt im Vergleich zu verbalem Lernen gibt, ist in vielen Studien die Reproduktionsleistung nach vorhergehender Beobachtung mit der nach Handlungsausführung vergleichbar. In der Tat legen neuere Ansätze der Handlungsgedächtnisforschung einen weitaus größeren Schwerpunkt auf die aktive Verarbeitung des zu erlernenden Materials. Übertragen auf das Erlernen von Routen impliziert dies, dass das räumliche Gedächtnis von Fahrern und Beifahrern vergleichbar gut sein könnte, wenn die aktive Verarbeitung räumlicher Informationen gesichert ist. Ein ähnlicher Vergleich von verschiedenen Lernbedingungen im Bereich räumlicher Kognitionsforschung wird unter dem Stichwort „Aktive Navigation“ geführt. Die Forschung zur aktiven Navigation beruht auf dem Grundgedanken, dass die eigenkontrollierte und freie Navigation für räumliches Lernen mehr fördert als eine passivere und vorrangig beobachtende

Navigation. Diese Annahme wurde bisher nahezu ausschließlich in virtuellen Umgebungen getestet. In der Literatur findet sich dabei eine vergleichbare Anzahl von Studien diese Annahme bestätigender wie sie widerlegender Studien. Als Grund für die uneinheitlichen Befunde haben verschiedene Autoren bereits uneinheitliche Definitionen und Konzeptualisierungen von aktiver Navigation diskutiert.

Serie 1 diente der Identifizierung und Entwirrung verschiedener, in der Forschung zur aktiven Navigation diskutierter Faktoren unter Verwendung virtueller Umgebungen (*N* = 275). Ausgehend von einer Fahrer/Beifahrer-Situation war die Kontrolle der Bewegung (im Sinne eigenkontrollierter respektive beobachteter Bewegung) der zentrale Faktor. Diese Unterscheidung findet sich auch in den meisten anderen Studien zu aktiver Navigation. Dementsprechend wurde die Bewegungskontrolle als erster Faktor manipuliert und vier anderen Faktoren gegenübergestellt, die in der Forschung zur aktiven Navigation diskutiert werden. Experiment 1 beschäftigte sich mit dem Einfluss der Lernintention, die von manchen Autoren als möglicher konfundierender Faktor diskutiert wurde. Weil die Mehrheit der Experimente jedoch im Labor erhoben werden, kann davon ausgegangen werden, dass die Teilnehmer eine Testung erwarten. Diese bereits aus der Situation entstehende Lernintention überschattet möglicherweise andere Effekte. Experiment 2 beschäftigte sich mit den möglichen Einflüssen von Instruktionsspezifität und Instruktionskontrolle. Befunde zur Zielspezifität implizieren, dass selbst kleine Unterschiede in den Navigationsinstruktionen bereits das räumliche Gedächtnis beeinflussen können. Bezüglich der Instruktionskontrolle erscheint es plausibel, dass räumliche Informationen nach aktivem Lesen besser verarbeitet werden als nach passivem Hören. Die Instruktionsspezifität wurde mittels verschiedener schriftlicher Instruktionen manipuliert, die entweder nur aus Landmarken-Informationen bestanden oder aber zusätzliche Überblicksinformationen enthielten. Wenn also Fahrer die Navigationsinstruktionen selber lesen und diese Instruktionen überdies spezifische räumliche Informationen betonen (zum Beispiel Übersichtsinformationen), entwickeln sie möglicherweise besseres Überblickswissen. Daraus folgt, dass ein solcher Vorteil weniger einen Effekt der Bewegungskontrolle, als vielmehr einen Effekt von Instruktionsspezifität oder Instruktionskontrolle darstellen könnte. Experiment 3 erweiterte diesen Ansatz mittels kartenbasierter Instruktionen, die navigatorische Entscheidungen verlangten. Eine Reihe von Studien betont, dass Entscheidungskontrolle in der aktiven Navigation eine wichtigere Rolle spielen könnte als die Bewegungskontrolle, dass also ein navigierender Beifahrer bessere Lernleistung räumlicher Informationen zeigen könnte als ein Fahrer. Die Teilnehmer erhielten daher in einer aktiven Navigationsbedingung Kartenausschnitte, auf denen der optimale Weg selbst identifiziert werden musste, während Teilnehmer in einer passiven Navigationsbedingung dieselben Kartenausschnitte erhielten, auf denen der optimale Weg bereits eingezeichnet war. Eine Kontrollgruppe erhielt keine Kartenausschnitte.

In allen drei Experimenten war das Landmarken-Wissen (gemessen mit einem Rekognitionstest) nach eigenkontrollierter Bewegung besser als nach beobachteter Bewegung, während die übrigen Manipulationen wenig Einfluss zeigten. Der Aufbau von Überblickswissen (gemessen mit einem Orientierungstest und einem Tour-Integrations-Test, in dem die mentale Repräsentation der Umgebung durch das Einzeichnen der Route in eine schematische Karte getestet wurde) wurde dagegen deutlich von weiteren Faktoren beeinflusst. Experiment 3 impliziert, dass aktive Entscheidungskontrolle in der Tat wichtiger ist als reine Bewegungskontrolle. In Experiment 2 hing ein Vorteil von eigenkontrollierter gegenüber beobachteter Bewegung von aktiver Instruktionskontrolle ab, insbesondere dann, wenn die Instruktionen zusätzliche Überblicksinformationen enthielten. Bei vorgelesenen Instruktionen fand sich dagegen kein Vorteil von eigenkontrollierter gegenüber beobachteter Bewegung. Hypothesenkonträr zeigte Experiment 1 keinen Vorteil von intentionalem gegenüber inzidentellem Lernen, und die Lernintention beeinflusste auch die Effekte der Bewegungskontrolle nicht. Zusammengefasst zeigt Serie 1, dass Bewegungskontrolle bezüglich Landmarkenwissen einen zentralen Faktor in der aktiven Navigation darstellt. Bezüglich des Aufbaus von Überblickswissen fand sich jedoch kein grundlegender Vorteil von eigenkontrollierter gegenüber beobachteter Bewegung. Dieser beruht vielmehr auf der aktiven Beschäftigung mit räumlichen Informationen.

Serie 2 übertrug diese Befunde auf einen realen Kontext, da sich die bisherige Forschung zu aktiver Navigation auf virtuelle Umgebungen oder die Übertragungsleistung von virtuellen auf reale Umgebungen beschränkte. Die Studien in realen Umgebungen, die am meisten Ähnlichkeiten zu aktiver Navigation aufweisen, beschäftigen sich mehr mit den Auswirkungen unterschiedlicher Instruktionseffekte als mit aktiver Navigation im hier diskutierten Sinne. Serie 2 stellt damit einen der ersten Versuche dar, zentrale Faktoren der aktiven Navigationsforschung in einem realem Kontext zu manipulieren (N = 232). Vergleichbar mit Experiment 3 wurden Bewegungskontrolle und Entscheidungskontrolle manipuliert. Teilnehmer fuhren auf dem Vorder- oder dem Rücksitz eines Tandems und erhielten verschieden ausführliche Kartenausschnitte, um durch einen Park zu navigieren.

Die Ergebnisse sind weitgehend übereinstimmend mit Serie 1. Das Steuern des Tandems als Fahrer ermöglichte besseres Landmarkenwissen im Vergleich zur Rolle des Beifahrers, allerdings nur, wenn die Umgebung bereits vertraut war. Navigationskontrolle stellte sich als entscheidender für den Aufbau von Überblickswissen heraus als Bewegungskontrolle. Wenn die Umgebung unvertraut war, wurde die Leistung im Tour-Integrations-Test durch aktive Navigationskontrolle verbessert, nicht jedoch durch aktive Bewegungskontrolle (Experiment 4). Wenn die Umgebung vertraut war, ermöglichte dies den Fahrern, die Nachteile passiver Navigation auszugleichen (Experiment 5). Freie Orientierungsaufgaben erbrachten keine auswertbaren Daten auf Grund von Einschränkungen durch den Experimentablauf selbst und natürliche Einschränkungen des Parks. Dies stellt eine mögliche Einschränkung der ökologische Validität dieser Studien dar. In Experiment 6 konnte der Tour-Integrations-Test jedoch als valides Messinstrument von Überblickswissen bestätigt und die Interpretation damit abgesichert werden. Weitere Unterstützung für diese Annahme lässt sich aus Experiment 3 ableiten, in dem aktive Navigationskontrolle nicht nur die Leistung im Tour-Integrations-Test, sondern auch die freie Orientierung von beobachtenden Teilnehmern positiv beeinflusste. Serie 2 impliziert also, dass aktive Navigationskontrolle auch in realen Kontexten wichtiger sein kann als das Steuern eines Fahrzeugs. Dies gilt besonders in unbekannten Umgebungen, während das Steuern eines Fahrzeuges in bekannten Umgebungen Nachteile passiver Navigation ausgleichen kann.

Zusammengefasst bestätigt die vorliegende Arbeit, dass räumliches Lernen in der Forschung zur aktiven Navigation zum größten Teil nicht von aktiver Bewegungskontrolle (also dem Steuern eines Fahrzeugs) bestimmt wird, sondern von der zwingenden Teilhabe am navigatorischen Prozess. Wenn die Situation Beifahrer zum notwendigen Verarbeitungslevel zwingt, entsteht kein Nachteil in punkto Überblickswissen. Im Kontrast dazu legen die Daten allerdings die Annahme eines grundsätzlichen Vorteils von Fahrern im Hinblick auf Landmarken-Wissen nahe. Die vorliegenden Studien tragen durch den Vergleich verschiedener, relevanter Faktoren in ausbalancierten Versuchspläne zur Klärung der existierenden Diskrepanzen in der aktiven Navigationsforschung bei. Sie zeigen außerdem mittels einer der ersten Realisierungen aktiver Navigation in einer realen Umgebung überhaupt, dass die Erforschung von räumlicher Kognition in virtuellen Umgebungen ökologisch valide Schlüsse auf reale Kontexte ermöglicht.

Lebenslauf

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Ausbildung

02/07 **Diplom**, Psychologie, Universität Trier
Titel: The Fast and the Smart: Does Fluid Intelligence Moderate the IAT Effect?
Betreuer: Prof. Dr. Melanie C. Steffens; Prof. Dr. Karl F. Wender, Universität Trier. Gesamtnote: 1,7.

10/03 **Vordiplom**, Psychologie, Universität Trier. Gesamtnote: 2,7.

06/99 **Abitur**, Arndt-Gymnasium, Krefeld. Gesamtnote: 2,1.

Wissenschaftliche Erfahrung und Berufstätigkeit

Seit 11/0 p7 **Wissenschaftlicher Mitarbeiter** bei Prof. Dr. Melanie C. Steffens, Abteilung für Psychologie (Nebenfach): Schwerpunkte Soziale Kognition und Kognitive Psychologie, Friedrich-Schiller Universität Jena.

02/07-05/07 **Forschungspraktikum** bei Prof. Dr. Jamin Halberstadt, Social Cognition Laboratory University of Otago, New Zealand.

04/07-05/05 **Forschungspraktikum** bei Prof. Dr. Melanie C. Steffens, Friedrich-Schiller Universität Jena.

09/04-02/05 **Hiwi-Tätigkeit** bei Dr. Melanie C. Steffens, Universität Trier.

Publikationen

Veröffentlichungen

von Stülpnagel, R., & Steffens, M. C. (2010). Prejudiced or just smart? Intelligence as a confounding factor in the IAT effect. *Zeitschrift für Psychologie/Journal of Psychology*, 218, 51-53.

Ebert, I. D., Steffens, M. C., von Stülpnagel, R., & Jelenec, P. (2009). How to like yourself better, or chocolate, less: Changing implicit attitudes with one IAT task. *Journal of Experimental Social Psychology*, 45, 1098-1104.

Vorträge

von Stülpnagel, R., Poppitz, S., & Steffens, M. C. (2011). *Vergleich von räumlichem Gedächtnis nach eigenkontrollierter und beobachteter Bewegung in virtuellen Umgebungen: Einflüsse von Intention und aktiver Navigation*. 53. Tagung experimentell arbeitender Psychologen, Halle, 13.-16.3.2011.

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Ehrenwörtliche Erklärung

Hiermit erkläre ich, dass mir die Promotionsordnung der Fakultät für Sozial- und Verhaltenswissenschaften an der Friedrich-Schiller-Universität Jena bekannt ist.

Weiterhin erkläre ich, dass ich die vorliegende Dissertation selbst und ohne unzulässige Hilfe Dritter angefertigt habe. Keine weiteren Personen waren bei der Auswahl und Auswertung des Materials beteiligt. Alle benutzten Hilfsmittel und Quellen sind in der Arbeit angegeben.

Ich habe weder die Hilfe eines Promotionsberaters in Anspruch genommen, noch haben Dritte unmittelbar oder mittelbare geldwerte Leistungen von mir für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der Dissertation stehen.

Die Arbeit wurde weder im In- noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde vorgelegt. Ich habe weder früher noch gegenwärtig an einer anderen Hochschule eine Dissertation eingereicht.

Ich versichere, dass ich nach bestem Wissen und Gewissen die Wahrheit gesagt habe und nichts verschwiegen habe.

Jena, den 18. März 2011 Rul von Stülpnagel