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ORIGINAL ARTICLE

Active route learning in virtual environments: disentangling movement control from intention, instruction specificity, and navigation control

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Abstract Active navigation research examines how physiological and psychological involvement in navigation benefits spatial learning. However, existing conceptualizations of active navigation comprise separable, distinct factors. This research disentangles the contributions of movement control (i.e., self-contained vs. observed movement) as a central factor from learning intention (Experiment 1), instruction specificity and instruction control (Experiment 2), as well as navigation control (Experiment 3) to spatial learning in virtual environments. We tested the effects of these factors on landmark recognition (landmark knowledge), tour-integration and route navigation (route knowledge). Our findings suggest that movement control leads to robust advantages in landmark knowledge as compared to observed movement. Advantages in route knowledge do not depend on learning intention, but on the need to elaborate spatial information. Whenever the necessary level of elaboration is assured for observed movement, too, the development of route knowledge is not inferior to that for self-contained movement.

Introduction

In modern times, one common way to get to know a new route is to be the driver or the passenger of a vehicle. Reflecting on this situation, people often claim that it is easier for them to memorize a route when driving (i.e., when controlling movement) instead of being the passenger (i.e., when observing this movement). This claim is addressed in research on 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, observational encounter of the same environment. Active navigation has been studied almost exclusively in virtual environments, as virtual environments allow a comprehensive control of environmental specifics and measurements, with spatial learning being comparable to that in real environments in many respects (e.g., Ruddle, Payne, & Jones, 1997; Waller, 2000; Witmer, Bailey, & Knerr, 1996). However, the empirical findings are inconsistent: Whereas several studies have supported the idea of a learning advantage of active over passive navigation (e.g., Bakdash, Linkenauger, & Proffitt, 2008; Carassa, Geminiani, Morganti, & Varotto, 2002; Hahm et al., 2007; Péruch, Vercher, & Gauthier, 1995; Wallet, Sauzéon, Rodrigues, & N'Kaoua, 2008), this assumption has been questioned by a similar number of studies that found few if any differences (e.g., Gaunet, Vidal, Kemeny, & Berthoz, 2001; Wilson, 1999; Wilson, Foreman, Gillett, & Stanton, 1997).

The aim of the present study is to clarify the diverging findings by disentangling factors relevant for spatial learning frequently comprised in active navigation research. Our approach to this analysis is based upon considerations what is central to navigation in real world situations. Central to any form of navigation is movement (i.e., locomotion through an environment, see Montello, 2005; Wiener, Ehbauer, & Mallot, 2009, for similar distinctions between different levels of navigation). Thus, we consider movement control (i.e., self-contained vs. observed movement, ajar to a driver/passenger situation) as a central element in active navigation. However, many

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qualities that make self-contained movement appear superior to observed movement are not inherent to self-contained movement, but rather go along with it frequently: first, people who control movement are more forced to attend to their environment closely than participants who observe this movement. However, it is possible that people who observe a route with the intention to remember it may be equally attentive to the environment. Thus, the intention to learn about spatial properties may compensate for differences between self-contained and observed movement. Second, in many real world situations, a driver is required to study and comply with a series of navigational instructions. However, a passenger may read the instructions to the driver in order to enable the latter to focus on driving. It is possible that the linking of provided spatial information to the actual spatial properties depends on this instruction control. Furthermore, the specific kind of spatial information provided in the instructions influences spatial learning (Taylor, Naylor, & Chechile, 1999). The effects of instruction control and instruction specificity have not yet been accounted for in active navigation research. Finally, drivers are frequently responsible for navigation, but navigation is not limited to drivers: passengers can be assigned to the navigator role. Thus, a navigating passenger's spatial learning may match or even outperform the spatial learning of a driver who complies with the navigational decisions. In order to test whether a potential advantage of self-contained movement over observed movement for the memorization of a specific route is reduced, enhanced, or unaffected by such factors, the present research aims to independently manipulate movement control in addition to these other factors.

Before we review the evidence on each of these factors in turn further below, we must briefly discuss two other factors relevant in active navigation research. First, it appears that the type of spatial knowledge test applied influences whether active navigation appears superior to passive navigation (see Brooks, Attree, Rose, Clifford, & Leadbetter, 1999; Péruch & Wilson, 2004, for further discussions). Commonly, three types of spatial knowledge are differentiated when measuring spatial knowledge: landmark knowledge refers to information about distinctive and stable features of the environment (frequently measured with recognition tasks). Route knowledge refers to information about the order of appearance of such landmarks and information about turns on a given route (and can, for example, be measured with route repetition tasks). Survey knowledge provides information about spatial relations of features in the environment in the form of a cognitive map including many features of a real map such as Euclidean properties of physical space (e.g., Thorndyke & Hayes-Roth, 1982). Classic measures of survey knowledge include pointing toward landmarks that are out of sight and sketching maps of the environment. The original model as first introduced by Siegel and White (1975) proposed that spatial learning is a hierarchical process, but recent frameworks on the relation of the types of spatial knowledge have challenged this assumption (Montello, 1998; Taylor et al., 1999).

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 in most cases no advantage in classic survey knowledge tasks (but see Bakdash et al., 2008). Although active navigation does not appear to lead to general advantages in landmark knowledge tasks, such effects have been reported (e.g., Fenech, Drews, & Bakdash, 2010; Hahm et al., 2007). However, the majority of studies that used route navigation tasks report superior performance after active navigation (including Wallet et al., 2008). Thus, in the experiments below we use a variety of the most common spatial knowledge tests. Second, there have been different experimental conceptualizations of active navigation (see Farrell et al., 2003; Péruch & Wilson, 2004, for further discussions). In the present research, we focused on the effects of active navigation on memory for a specific route (e.g., Carassa et al., 2002) rather than on an unspecified exploration of an environment in general (e.g., Bakdash et al., 2008; Péruch et al., 1995; Wilson et al., 1997). Requiring a person to use a specific route is more similar to an actual navigation situation. It also eliminates several potential confounds (e.g., time of exposure). As a consequence, the development of a cognitive map of a given environment as assessed with survey knowledge tasks was of minor importance in this research.

The role of intention in spatial learning

The first factor we identified as a potential source of variance in spatial learning in drivers and co-drivers is learning intention. Regarding their finding of comparable spatial learning after active and passive navigation, Wilson and colleagues discussed 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 deliberate intention to learn about spatial properties compensates for differences between active and passive spatial learning. Indeed, classic works on the effect of intention on general memory performance suggest that intentional learning can exceed incidental learning. However, this advantage disappears if, for example, the incidental learning task also requires a semantic or meaningful elaboration of study materials (e.g., Hyde & Jenkins, 1969; Mandler, 1967), a finding that can be explained by different levels of processing (Craik & Lockhart, 1972). To our knowledge, there is as of yet no attempt to manipulate route learning intention in a virtual environment. However, a handful of studies in real environments have addressed this issue. An early study with children reported no differences between an intentional and an incidental learning condition (Herman, Kolker, & Shaw, 1982), as did another study that was not primarily concerned with route learning (Dayan & Thomas, 1994). 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 reported no effects in landmark knowledge, but superior performance in survey knowledge tasks after intentional, as compared to incidental, learning. These findings are interpreted by the authors as an automatic processing of landmark knowledge, whereas the development of survey knowledge requires effortful processing (see also Magliano, Cohen, Allen, & Rodrigue, 1995). If learning intention generally benefits the processing of survey knowledge, this may override effects of movement control and enable comparable memory performance after self-contained and observed movement.

Goal and instruction specificity

Another factor that may affect spatial learning during active navigation is people's expectations about the purpose of navigation as well as the nature of the available spatial information. This is emphasized in the concept of goal specificity, which postulates that spatial learning is affected by the intended goal (Taylor et al., 1999). A route goal enhances performance on route perspective tasks; a survey goal enhances performance on survey tasks (see also Fields & Shelton, 2006; Foo, Warren, Duchon, & Tarr, 2005; Rossano & Reardon, 1999; Shelton & McNamara, 2004). Differences in goal specificity may add 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 movement without any specific instruction may have automatically focused on the encountered route, enabling them to perform better, for example, in a route navigation task than participants who observed the movement.

The concept of goal specificity also implies that spatial knowledge is developed contingent upon 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 navigational instructions, such as the inclusion of either landmark or cardinal headings into verbal descriptions (e.g., Reagan & Baldwin, 2006). This implies that in a yoked experimental design (resembling a driver/passenger situation) where the participant who controls movement receives instructions where to move based on landmark information, an advantage in an corresponding landmark 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.

Movement control, navigation control, and instruction control

A third reason that may add to the impression of better spatial learning of drivers as compared to passengers is that movement control may be confounded with navigation control (e.g., Péruch et al., 1995). In a clever experimental design, Wilson and colleagues (1997) disentangled these factors. Resembling a driver/passenger situation, one participant controlled movement with computer keystrokes, the other participant observed this movement. Independent of movement control, one of them controlled navigation, the other did not make decisions. In contrast to their expectations, the authors found neither an effect of movement control nor of navigation control on spatial learning. However, the free exploration of the environment without a specific goal and the authors' choice of task (pointing and map drawing, see Wallet et al., 2008) may have contributed to this result. Subsequent studies that did not use completely counterbalanced designs were more successful in providing evidence that navigation control can be more central than movement control for route navigation performance (Carassa et al., 2002) and survey knowledge (measured by pointing accuracy and relative positioning of landmarks, Bakdash et al., 2008). Similarly, Farrell and colleagues (2003) demonstrated that the ability to transfer a wayfinding task from the virtual equivalent of a real environment to the real environment was enhanced by navigation control rather than by movement control. In conclusion, there is strong evidence that controlling navigation (i.e., the decision where to move) is more important than the execution of this movement. However, navigation control in the discussed studies referred to the free exploration of an environment (with or without instructions to identify an optimal route), and effects of exposure may thus limit the generality of the findings. Additionally, the reported studies tested either route or survey knowledge, whereas the effects of navigation control on landmark knowledge have been rarely examined (but see Fenech et al., 2010).

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-making, 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/passenger situation, it is possible that a passenger reads these instructions to the driver in order to enable the latter to focus on driving. The question is whether people who control the instructions (even if this instruction does not involve navigational decisions) encode spatial information better (as they are more likely to connect the navigational information of the instructions with the environment) or worse (as reading the instructions rather distracts 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.

Aims of the present research

To sum up, the present research aims to disentangle the role of movement control from four factors that potentially affect spatial learning and route memory in virtual environments. Thus, similar to a driver/passenger situation, participants were tested in pairs throughout all experiments, 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 additional factors, we manipulated learning intention in Experiment 1, instruction specificity and instruction control in Experiment 2, and navigation control in Experiment 3.

In line with previous findings, we expected self-contained movement to enable better performance than observed movement in a route navigation task, but comparable performance in abstract survey knowledge tasks (e.g., pointing and map-sketching). Findings regarding landmark knowledge have been mixed, thus we attempted to explore further whether manipulations of movement control affect landmark knowledge.

Experiment 1

Experiment 1 manipulated learning intention in addition to movement control in order to test whether intentional learning compensates for potential disadvantages of observed movement as compared to self-contained movement. In an 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 an 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. Spatial memory was evaluated with the most common spatial memory tests (i.e., a landmark recognition task as an indicator of landmark knowledge, a pointing task and a path-sketching task as indicators of survey knowledge, and a route navigation task as an indicator of applied route knowledge). Although we did not expect a specific effect in the landmark recognition task, we included landmarks that were more, or less, relevant for orientation (Miller & Carlson, 2011). Even if there is no general difference in landmark knowledge between self-contained and observed movement, this may still be the case for landmarks that are more relevant for navigation.

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 (van Asselen et al., 2006).

Method

Participants and design

Participants were 82 students (43 of them males, about equally distributed over all experimental conditions), ranging in age between 19 and 33 years, $M = 23.02$, $SD = 3.10$. The independent variables were movement control (self-contained vs. observed movement) and learning intention (intentional vs. incidental learning), manipulated between subjects. Dependent variables were landmark recognition, pointing accuracy, path-sketching, and route navigation. Given $\alpha = 0.05$ and $N = 82$, large between-subject effects ($f = 0.40$) could be detected with a statistical power of $1 - \beta = 0.95$ (Cohen, 1977).

Materials

A grid of 6×7 fields was used as a basis for a virtual environment resembling an urban environment with buildings, streets, and greens, 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 (see Fig. 1 for a schematic overview of the environment). Each field contained one landmark (e.g., a car, a statue, or a stack of boxes. Figure 2 provides a screenshot in first person perspective with a truck as an exemplary landmark). Among the encountered landmarks, 9 were passed by while continuing on a straight path (and were therefore of lower relevance for navigation), and 11 indicated a turn in the path (and were of higher relevance).

Auditory route instructions were prerecorded and covered information about the route for the next one–three fields. Every field's landmark 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. In order to ensure that the instructions were fully understood, they were automatically repeated until participants left the trigger field.

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 20 landmarks 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 identifying which had and had not been encountered on the previous route.

For the *pointing task*, the destination field was displayed on the computer screen. The destination field consisted of a small building open to one direction only and with a circle on the ground that showed the degrees from 0 to 360. Individually, participants were asked to look around 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 field. These features were the start field and two other main buildings passed in the environment, which were shown as pictures. None of them was visible from the destination field. Performance was evaluated by computing the mean angular difference between the indicated and the actual directions of the landmarks, with 0° indicating perfect pointing accuracy and 180° indicating pointing into the opposite direction.

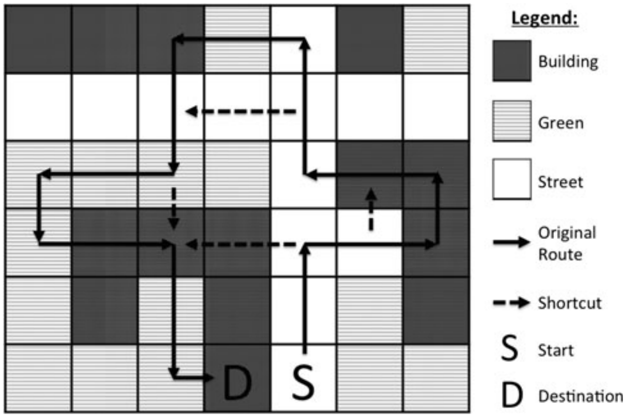

Fig. 1 Map of the environment used in Experiment 1

We prepared a *path-sketching task* instead of a traditional map-sketching task, because only few studies on active navigation found differences in free map-sketching tasks. In this task, participants received a sheet of paper with an empty grid of 6 × 7 fields and were asked to draw the outline of the previously encountered route into the grid from the indicated start field. Performance in this task was evaluated by subtracting the number of incorrect fields from the number of correct fields and dividing the resulting score by the overall number of marked fields. This computation ranges between −1 and 1, the latter score indicating perfect performance. A score of 0 indicates that an equal number of correct and incorrect 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 to incorrect fields is 21:20).[1]

For the *route navigation task*, the environment was reloaded so that the virtual camera was positioned on the start field again, and every participant was individually asked to take the fastest way to the destination field. Thus, participants could use shortcuts in this task. However, shortcuts were not mentioned explicitly, because we assumed that doing so could result in participants focusing

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[1] This computation was chosen for continuity reasons throughout this research (i.e., the tour integration task used in Experiments 2–3). However, it does not exclude the possibility that a participant can first draw one wrong turn followed by correct turns, which results in a potential underestimation of this participant's performance. We considered several alternative computation approaches, for example, to count whether two subsequent turns were correctly indicated (e.g., the original route included first a left turn, followed by a right turn. A correct indication of those turns would account one point). However, the overall quality of the sketched paths was rather low, so that it was impossible to determine which drawn turn corresponded to which turn of the original route. Due to the difficulties to establish a meaningful objective scoring criterion, we decided to rate subjectively how similar the sketched path was as compared to the original route (ranging from 1 = no similarity to 5 = absolute congruence; $M = 2.23$, SD = .86). The same ANOVA as reported in the results section showed no significant effects, all Fs < 1.18, *ns*. We conclude that participants of all experimental conditions were unable to deduce the cross-shape of the route from their egocentric encounter of the environment. In other words, they did not develop a cognitive map of the environment.

Fig. 2 A screenshot in first person perspective from the environment used in Experiment 1. The truck was used as a landmark in the audio instructions and the recognition task

on an errant search for potential shortcuts rather than relying on their spatial memory. We reasoned that participants who had actively navigated and encoded the environment would be more likely to detect and use shortcuts, and thus more likely to arrive faster at the destination field than more passively navigating participants, who were more likely to follow the original route. The computer automatically recorded the performance in this task including exact time and chosen route for subsequent analysis. Performance was evaluated by the time in seconds participants required to find the destination room, with increasing time indicating poorer performance.

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

Procedure

Participants were randomly assigned to either 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 both experimental conditions were individually introduced to movement control and the automatic auditory instructions in a small practice environment for about 1 min. The study phase was conducted in pairs of two participants. Both participants sat 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 note the time with a stopwatch as well as to monitor their partner's path and guide them not to take false turns. A steady time ($M = 128$ s, SD = 19) and very few indications of false turns that had to be corrected by the observing participants ($M = 0.15$, SD = 0.54) showed that navigating the environment worked well, with no differences between the intentional and the incidental learning conditions in two separate ANOVAs, both $F\text{s} < 1.34$, ns.

In the test phase, participants were seated in front of G4 iBooks in separate booths. After an unrelated distracter task of about 2 min length, the pointing task, landmark recognition task, path-sketching task, and route navigation task were administered 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 demographics and the second questionnaire after about 30 min.

Results

For all statistical analyses throughout this paper, the Type-I-error was set at $\alpha = 0.05$. As an indicator of the effect size, partial η^2 (η_p^2) is reported for statistically significant effects (Cohen, 1977). Preliminary analyses for potential effects of sense of orientation, computer game experience, and gender are reported in the "Appendix".

Landmark recognition

We assumed that landmarks that indicated a turn would be more relevant to navigation and thus easier to recognize than landmarks that were passed on a straight path. 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 showed no main or interaction effects on false alarm percentage, all $F\text{s} < 1$.

For the analysis of hits percentage, we computed a 2 (movement control) × 2 (learning intention) × 2 (landmark

Table 1 Descriptive mean (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)		0.18 (0.25)	0.22 (0.24)	0.27 (0.24)	0.21 (0.30)
Route navigation *M* (SD)		98 s (64)	101 s (30)	120 s (54)	119 s (41)

Performance proportions of false alarms and hits are reported in the landmark (LM) 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). Route navigation performance is presented in average time in seconds needed to move from start to destination

relevance: indicating turns vs. passed straight) ANCOVA with repeated measurement on the last factor. As 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, $F(1,78) = 7.75, p < 0.01, \eta_p^2 = 0.09$, and showed a main effect of movement control, $F(1,78) = 4.54, p < 0.04$, $\eta_p^2 = 0.06$. There was no main effect of learning intention, $F < 1$. Further, there was an interaction of movement control and landmark relevance, $F(1,78) = 4.28$, $p < 0.05$, $\eta_p^2 = 0.05$. An analysis of simple main effects showed that landmarks that indicated turns were better recognized by participants in the self-contained movement condition as compared to participants in the observed movement condition, $F(1,78) = 11.45$, $p = 0.001$, $\eta_p^2 = 0.13$ (all other Fs < 1)[2]. Taken together, the data suggest better memory for landmark after self-contained movement, but no effect of learning intention on landmark knowledge.

Pointing accuracy and path-sketching

As seen in Table 1, performance in both tasks was poor, 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 (although a t test confirmed that participants did perform better than a chance level of 90°, $t(80) = -3.35$, $p < 0.001$). Separate 2 (movement control) × 2 (learning intention) ANOVAs revealed no significant main or interaction effects for either dependent variable, all Fs < 1.84, ns. Thus, movement control did not affect survey knowledge as assessed with these tasks. 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.

Route navigation

Route navigation time was log-transformed to achieve a normal distribution of the data (but is presented in seconds in Table 1 for clarity). Self-contained movement resulted in faster performance than observation. A 2 (movement control) × 2 (learning intention) ANCOVA confirmed this impression by showing a main effect of movement control, $F(1,74) = 4.95$, $p < 0.03$, $\eta_p^2 = 0.06$. There was neither a main effect of intention nor an interaction effect, both Fs < 1. Thus, in line with previous studies, self-contained movement benefitted route navigation performance. In contrast, performance was comparable after intentional and incidental learning.

It can be argued that this reported effect resulted from increased movement practice of participants in the self-contained movement condition during the study phase, despite our efforts to avoid such a confound with the initial practice trial. Thus, we analyzed the recordings for the number of fields that were encountered during the route navigation task, as well as for the number of used shortcuts. Two separate one-way ANOVAs (self-contained movement vs. observed movement) 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), $F(1,79) = 8.60$, $p < 0.01$, $\eta_p^2 = 0.10$. 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 $M = 22.03$, $SD = 1.14$,

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[2] There was an interaction of intention and landmark relevance, $F(1,78) = 4.49$, $p < 0.05$, $\eta^2 = 0.05$, 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, however, because it is of little interest for active navigation effects.

respectively), $F(1,78) = 4.02$, $p < 0.05$, $\eta_p^2 = 0.05$. Thus, self-contained movement led to faster route navigation because a more efficient route was identified, not due to more movement practice.

Discussion

Experiment 1 tested the effects of self-contained versus observed movement and intentional versus incidental learning on spatial learning. Regarding the effects of movement control, our findings are in line with previous research: self-contained movement enabled better route navigation 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, but only if the landmarks were of some relevance for navigation. Thus, self-contained movement provided advantages over observed movement in tasks that require landmark and route knowledge, rather than in classic survey knowledge tasks.

The null-effects in the survey knowledge tasks are in line with previous findings (Wallet et al., 2008). 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, as indicated by the very poor performances throughout all conditions. In order to analyze differences of self-contained and observed movement, it thus seems appropriate to focus on spatial tasks that assess memory for a specific route.

We manipulated learning intention as the second independent factor and expected effects in survey knowledge, but not in landmark knowledge. However, intentional learning yielded few if any advantages 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). Future approaches could try to develop incidental instructions that are even less related to the task of navigating an environment than the instructions used in this experiment. However, experimental instructions completely unrelated to any form of spatial or navigational tasks are hard to conceive, especially for a self-contained movement condition. In conclusion, we found little evidence that intentional learning benefits spatial 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. If participants in the observed movement condition are more involved in the navigation process and required to process the navigation instructions, they may develop comparable spatial knowledge to participants in the self-contained movement condition.

Experiment 2

Previous research suggests that the availability and the processing of specific spatial information is crucial to spatial learning (Taylor et al., 1999). Thus, Experiment 2 was designed to manipulate instruction control and instruction specificity in addition to movement control, factors that have not been yet addressed in active navigation research. Navigational instructions were not presented automatically to both participants as in Experiment 1. Independent of movement control, one participant was assigned the navigator role and verbally instructed the other, listening participant where to move. Regarding instruction specificity, the navigating participants received instructions that either contained landmark information only (comparable to Experiment 1), or additional layout information (see Reagan & Baldwin, 2006; Zimmer, 2004, for similar approaches).

Based on the results of Experiment 1, we concentrated on landmarks relevant for navigation. Furthermore, the measures intended to measure survey knowledge tasks were not sensitive to our experimental manipulations, and also less suitable to analyze the effects of movement control as compared to other factors on memory for a specific route. Thus, we refrained from using a pointing task, and changed the path-sketching task to a tour-integration task, where participants were required to reconstruct the encountered route in an abstracted map of the environment.

If instruction control is a factor crucial to spatial learning, we can expect better performance from participants who instruct someone else compared to those who only listen to someone else's instructions. On the one hand, instruction control might compensate for disadvantages in spatial learning if it assures a greater involvement in navigation of participants who observe movement. On the other hand, instruction control may further increase the advantage of self-contained movement if it leads participants who control their movement to focus 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) to affect landmark knowledge tasks only. Conversely, we expect that navigation instructions that consist of additional layout information (e.g., about the shape of a room that has to be crossed) will benefit the ability to reconstruct and repeat a specific route. If instruction specificity is separated from movement control, disadvantages of observed movement as compared 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.

Method

Participants and design

Participants were 94 students (10 males), ranging in age from 18 to 33 years, $M = 21.02$ years, SD $= 2.80$. Due to an apparatus failure, data of two participants were incomplete. Another four participants performed far below average (-3 SDs) in either the recognition task or the tour-integration task and were excluded from further analyses. The remaining 88 participants were tested in a $2 \times 2 \times 2$ study design with the independent variables movement control (self-contained vs. observed movement), instruction control (instructing vs. listening), and instruction specificity (landmark information vs. layout information), manipulated between subjects. Dependent variables were landmark recognition, tour integration, and route navigation. Given $\alpha = 0.05$ and $N = 88$, large between-subjects interaction effects ($f = 0.40$) could be detected with a statistical power of $1 - \beta = 0.96$ (Cohen, 1977).

Materials

Materials, apparatus, and procedure were 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 the start and destination. Each room was also connected to a third dead-end room, resulting in a total of 18 rooms. When constructing the environment, care was taken that dead-ends mostly ended adjacently to other rooms (but without a connection between them, see Fig. 3). One landmark was positioned in every main room, resulting in a total of eight landmarks. Movement was controlled with the arrow keys.

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 layout 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!”). Thus, although these instructions do not represent survey information in the original sense (i.e., they provide navigation information from an egocentric rather than from an allocentric point of view), they should enable participants to develop a more structured memory about their surrounding than instructions that mention landmarks only.

For the *recognition task*, screenshots of all eight landmarks as well as screenshots of eight distracter landmarks were prepared. Participants were presented with four original and four distracter landmarks in quasi-randomized and counterbalanced order and asked to indicate whether or not they had seen these landmarks.

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 to draw a line connecting start and destination (see Fig. 4). Due to the multiple possibilities to draw this line, the correct route cannot be deduced, but must be reconstructed by recalling spatial properties of the rooms encountered during the study phase. Computation of performance scores was identical to the path-sketching task in Experiment 1.[3]

In the *route navigation task*, the environment was reset to the start, and participants were instructed to find the destination as quickly as possible.

Procedure

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 (either in the landmark information only version, or in the additional layout information version) and mentioned all instruction information aloud to the listening partner. This resulted in two possible pairings. In one pairing, the participant who controlled movement but did not control

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[3] Similar tasks have been used as measures of survey knowledge (van Asselen et al., 2006), which correlated with established survey knowledge tasks such as landmark pointing (von Stülpnagel & Steffens, 2012). However, the tour-integration task resembles a route knowledge task in many regards, as it can be solved by recalling the consecutive order of differently shaped rooms. Thus, in the present experimental setting, an advantage in tour integration performance represents an advantage in the ability to reconstruct a specific route (i.e., route knowledge) rather than in development of a cognitive map (i.e., survey knowledge).

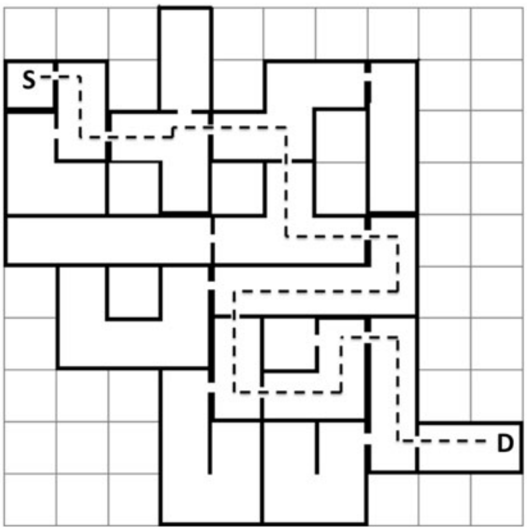

Fig. 3 Map of the environment used in Experiment 2. *Black lines* represent walls. All connections between rooms are indicated. The *dotted line* represents the intended route from start room (*S*) to destination (*D*)

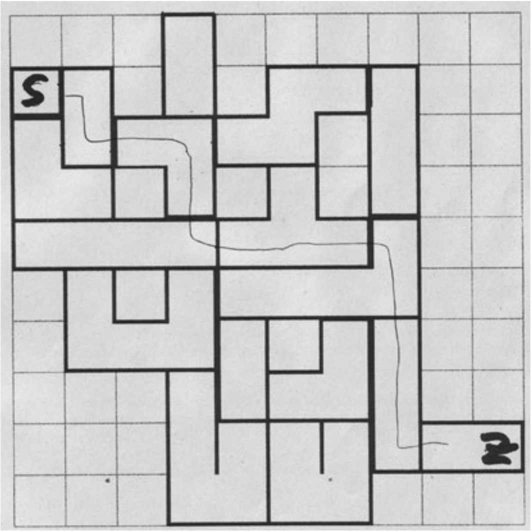

Fig. 4 Example of tour-integration performance taken from the data sample of Experiment 2. Note that connections between rooms are not indicated in this version of the map. The *thin pen-line* displays the route indicated by the participant. The *Z* responds to "Ziel" (German for destination)

instruction information listened to all directions given by the observing partner, who, in turn, 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 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 distracter task for about 2 min, followed in the reported order by the tour-integration task, the landmark recognition task, and the route navigation task. Demographic data and computer game experience were assessed before debriefing.

Results

The analysis of potential confounding factors (i.e., gender and computer game experience) is reported in the "Appendix".

Landmark recognition

For false alarm percentage, the only significant effect in a 2 (movement control) × 2 (instruction control) × 2 (instruction specificity) ANOVA was a second-grade interaction of all three factors, $F(1,80) = 12.11, p = 0.001, \eta_p^2 = 0.13$ (all other Fs < 3.71, ns). As we had no hypothesis for such a specific interaction, we refrain from interpreting this effect.

As derived from Table 2, there were more hits after self-contained than after observed movement. The corresponding 2 × 2 × 2 ANOVA corroborated this impression, $F(1,80) = 6.80$, $p < 0.02$, $\eta_p^2 = 0.08$ (all other Fs < 1.84, ns). Thus, movement control, but neither instruction control nor instruction specificity affected landmark knowledge.

Tour integration

As derived from Table 2, layout information appeared to enable better tour-integration performance than landmark information, and this difference was more pronounced in the self-contained movement condition than in the observed movement condition. A 2 (movement control) × 2 (instruction control) × 2 (instruction specificity) ANOVA corroborated this impression, with a main effect of instruction specificity, $F(1,80) = 9.00$, $p < 0.01$, $\eta_p^2 = 0.10$, qualified by an interaction of instruction specificity and movement control, $F(1,80) = 5.27$, $p < 0.03$, $\eta_p^2 = 0.06$. An analysis of simple main effects showed that self-contained movement with layout information resulted in better performance than observed movement with layout information, $F(1,80) = 8.07$, $p < 0.01$, $\eta_p^2 = 0.09$, as well as self-contained movement with landmark information, $F(1,80) = 16.87$, $p < 0.001$, $\eta_p^2 = 0.17$ (all other Fs < 1). Thus, in line with our hypothesis, the additional layout

Table 2 Descriptive mean (and standard deviations) of all dependent variables in experiment 2, separately for all experimental conditions

	Self-contained movement				Observed movement			
Condition	Instructing		Listening		Instructing		Listening	
Task	Layout information	Landmark information	Layout information	Landmark information	Layout information	Landmark information	Layout information	Landmark information
LM false alarms *M* (SD)	9 % (12)	10 % (13)	2 % (7)	15 % (20)	11 % (20)	25 % (20)	23 % (18)	3 % (8)
LM hits *M* (SD)	88 % (19)	79 % (20)	88 % (13)	88 % (13)	79 % (22)	78 % (22)	70 % (20)	73 % (22)
Tour-integration *M* (SD)	0.63 (0.28)	0.35 (0.32)	0.62 (0.30)	0.25 (0.22)	0.24 (0.16)	0.39 (0.26)	0.51 (0.30)	0.27 (0.31)
Route navigation *M* (SD)	85 s (64)	93 s (28)	98 s (47)	159 s (92)	145 s (40)	133 s (73)	109 s (76)	116 s (34)

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

information benefitted the mental reconstruction of the route—but only for participants who controlled movement.

We also found an unexpected interaction effect of instruction specificity and instruction control, $F(1,80) = 3.96$, $p = 0.05$, $\eta_p^2 = 0.05$. An analysis of simple main effects indicated that listening to layout information resulted in better tour-integration performance than instructing with layout information, $F(1,80) = 12.88$, $p = 0.001$, $\eta_p^2 = 0.14$ (all other Fs < 2.24, ns). We speculate that participants who read the more detailed layout information instructions were somewhat distracted, whereas participants who listened to the instructions were able to match the information with the environment more easily. There were no other significant main or interaction effects, all Fs < 3.31, ns.

Route navigation

Route navigation 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 landmark information, see Table 2). A 2 (movement control) × 2 (instruction control) × 2 (instruction specificity) ANCOVA revealed a main effect of movement control, $F(1,79) = 4.76$, $p < 0.04$, $\eta_p^2 = 0.06$, qualified by an interaction of movement control and instruction control, $F(1,79) = 8.07$, $p < 0.01$, $\eta_p^2 = 0.09$ (all other Fs < 3.32, ns). The analysis of simple main effects indicated that the combination of self-contained movement and instructing a partner resulted in better route navigation performance than self-contained movement and listening to a partner, $F(1,79) = 7.61$, $p < 0.01$, $\eta_p^2 = 0.09$, as well as better performance than observed movement in combination with instructing a partner, $F(1,79) = 12.24$, $p = 0.001$, $\eta_p^2 = 0.13$. Thus, participants in the self-contained movement condition were only able to apply navigational information in the route navigation task when they had read it themselves, but not when they had listened to it.

Discussion

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

Regarding landmark recognition, participants who controlled movement showed better performance than participants who observed this movement as in Experiment 1. Moreover, this advantage appeared robust across all levels of instruction control and instruction specificity. Thus, we conclude that self-contained movement may provide an inherent advantage over observed movement regarding landmark knowledge. However, it should be noted that all landmarks were also named in the instructions of the layout information condition. This may have masked negative effects of layout information on landmark knowledge.

Both the tour-integration task and route navigation task provide evidence that instruction control and instruction specificity benefit spatial learning through self-contained movement. Tour-integration performance after self-contained movement was superior to performance after observed movement, but only when the instructions included additional layout information. In the route navigation task, the combination of controlling movement and giving instructions proved to be superior to all other conditions. Possibly, the combination of these factors with movement control exemplifies interactive context encoding (Baddeley, 1982), where the presented information becomes part of the specific action of maneuvering and is consequently better encoded. However, it remains an open question why the tour-integration task was mainly affected by information specificity and the route navigation task by instruction control, respectively, but not vice versa.

Taken together, instruction control and additional layout information seem to be critical for an advantage of self-contained as compared to observed movement in the mental reconstruction of a route and repeated route navigation. Viewed differently, this implies that spatial learning of self-contained and observed movement is rather comparable without instruction control and additional layout information. However, the present manipulations did not require navigational decisions, 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 navigation control, suggesting that deciding about where to move is more important than the actual execution of this 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, navigation control was manipulated in Experiment 3.

Experiment 3

In Experiment 3, we aimed to manipulate navigation control in addition to movement control. Previous studies realized navigation control by allowing a free exploration of an environment with or without movement control (e.g., Bakdash et al., 2008; Carassa et al., 2002; Wilson et al., 1997). However, in order to be consistent with Experiments 1–2, we attempted to test whether active navigation control affects spatial memory for a specific route. Unfortunately, it is difficult to induce navigation control with verbal descriptions of a specific route. Thus, active navigation control was realized by presenting a series of fragmented maps that required the participants to make a number of decisions about the correct course (see Münzer, Zimmer, Schwalm, Baus, & Aslan, 2006; von Stülpnagel & Steffens, 2012; Zimmer, 2004, for similar approaches). Navigation with maps can be expected to create a bias toward a survey representation (Taylor et al., 1999), and may result in a different mental representation of the environment than having seen no map (Willis, Hölscher, Wilbertz, & Li, 2009). Thus, it was mandatory to implement an experimental condition that included maps in order to ensure a comparable mental representation of the environment, in the absence of 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 design. Participants in the active navigation condition received fragmented maps that required decision-making and consisted of start and destination only. A careful design of the map fragments required these participants to identify and select 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 navigation control for better encoding of spatial information, we can expect the best tour-integration performance from participants in the combination of self-contained movement and navigation control. However, if navigation control is more relevant than movement control as suggested by previous research, navigation control, but not movement control, should determine tour-integration performance. A route navigation 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 active navigation control (i.e., the active processing of maps) enables participants in the observed movement condition to apply this survey information in the route navigation 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. Findings on goal specificity suggest that due to the specific information format of map segments, participants who navigate with maps may be prevented from encoding landmark information (e.g., Taylor et al., 1999).

Method

Participants and design

Participants were 102 students (21 males), ranging in age from 19 to 41 years, $M = 21.25$, SD $= 2.66$. Independent variables were movement control (self-contained movement vs. observed movement) and navigation control (active vs. passive vs. no navigation), manipulated between subjects. Dependent variables were identical to Experiment 2. Given $\alpha = 0.05$ and $N = 102$, large between-subject interaction effects ($f = 0.40$) could be detected with a statistical power of $1 - \beta = 0.95$ (Cohen, 1977).

Materials and procedure

The materials and procedure correspond to Experiment 2 if not mentioned otherwise. Another virtual environment was created. The intended route consisted of 3 segments with 24 rooms in total. Several dead-ends were included, resulting in an environment of 38 rooms. The intended route contained 16 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. Each map segment included 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 Fig. 5). Participants were asked to identify and use the shortest possible route. Participants in the passive navigation condition received identical map segments, but the shortest way was marked with a red line (see right panel of Fig. 5). 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.

To test landmark knowledge in a *recognition task*, screenshots of 16 landmarks as well as 16 distracter landmarks were used. Each participant was shown eight original and eight distracter 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. The *route navigation task* was identical to Experiment 2.

Results

An analysis of potential confounding factors (i.e., gender, computer game experience) is reported in the “Appendix”.

Landmark recognition

An analysis of false alarm percentage yielded no effects, all Fs < 1. The analysis of hit percentage with a 2 (movement control) × 3 (navigation control) ANOVA revealed a main effect of movement control, $F(1,96) = 4.30$, $p = 0.04$, $\eta_p^2 = 0.04$, and an effect of navigation control, $F(2,96) = 4.95$, $p < 0.001$, $\eta_p^2 = 0.09$, but no interaction effect, $F < 1$. As seen in Table 3, the number of hits was higher after self-contained as compared to observed movement. Post hoc tests (LSD) corroborated the impression that participants recognized more landmarks in the no-navigation condition than in the active navigation condition ($p = 0.001$) and somewhat more landmarks than in the passive navigation condition ($p = 0.06$), whereas there was no difference between the active and the passive navigation condition ($p = 0.28$). Thus, self-contained movement enabled better landmark knowledge as in the previous experiment, and navigating with maps deterred participants from encoding landmark knowledge as hypothesized.

Tour integration

Tour-integration performance was strongly affected by navigation 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 (navigation control) ANOVA, which revealed a strong effect of navigation control on tour-integration performance, $F(2,96) = 42.88, p < 0.001, \eta_p^2 = 0.47$, and a main effect of movement control, $F(1,96) = 6.59$, $p < 0.02$, $\eta_p^2 = 0.06$. These effects were qualified by an interaction of both factors, $F(2,96) = 3.97, p < 0.03, \eta_p^2 = 0.08$. 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, $F(1,96) = 16.44$, $p < 0.001$, $\eta_p^2 = 0.15$, for the other navigation conditions Fs < 1. A simple

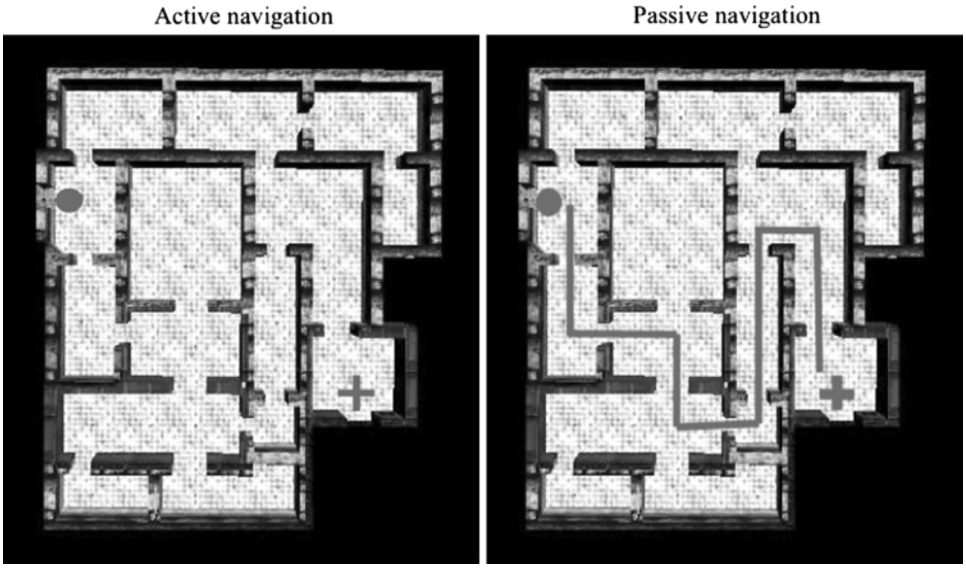

Fig. 5 The second map segment as it was presented to the participants in Experiment 3. In the active navigation condition, only start and destination are indicated. In the passive navigation condition, a line indicates the optimal course between start and destination

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)	0.48 (0.20)	0.48 (0.19)	0.21 (0.20)	0.70 (0.14)	0.51 (0.14)	0.23 (0.10)
Route navigation *M* (SD)	165 s (57)	149 s (56)	157 s (56)	193 s (64)	224 s (66)	169 s (70)

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

main effect in the observed movement condition, $F(2,96) = 36.25$, $p < 0.001$, $\eta_p^2 = 0.43$, indicated that active navigation exceeded passive navigation ($p < 0.01$) and no-navigation ($p < 0.001$), and passive navigation exceeded no-navigation ($p < 0.001$). In contrast, a simple main effect for the self-contained movement condition, $F(2,96) = 13.21$, $p < 0.001$, $\eta_p^2 = 0.22$, indicated that active and passive navigation differed from no-navigation (both *p*s < 0.001), but not from each other ($p > 0.05$). Thus, a reconstruction of the previously encountered route as tested with the tour-integration task was mainly enabled by the availability of allocentric information (i.e., the map segments), but not by self-contained movement. On the contrary: participants in the observed movement condition were even more able to integrate active navigation into a reconstruction of the route than participants in the self-contained movement condition.

Route navigation

Route navigation performance after observed movement was comparable to performance after self-contained movement in the active navigation condition and in the no-navigation condition, but distinctively worse in the passive navigation condition (see Table 3). Route navigation time was log-transformed and included in a 2 (movement control) × 3 (navigation control) ANCOVA. There was a main effect of movement control, $F(1,94) = 11.87$, $p = 0.001$, $\eta_p^2 = 0.11$, no effect of navigation control, $F < 2.10$, ns, but an interaction of both factors, $F(2,94) = 3.02$, $p = 0.05$, $\eta_p^2 = 0.06$. Analyses of simple main effects revealed a significant advantage of self-contained over observed movement for passive navigation, $F(2,94) = 14.67$, $p < 0.001$, $\eta_p^2 = 0.14$, that was absent for active navigation and for the no-navigation condition, both *F*s < 3.05, ns. Thus, active navigation enabled participants who observed movement to compensate for disadvantages in route navigation.

Discussion

Experiment 3 pitted movement control against navigation control using map-based instructions. 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 the type of map-based instructions. One could argue that a better mental representation of maps after more active encoding of these maps is not particularly surprising, especially as an exposure to the environment may not have been actually 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. In other words, this finding implies that self-contained movement does not provide advantages for spatial memory per se.

More importantly, navigation control affected route navigation performance: only in the passive navigation condition did observed movement result in significantly slower route navigation than self-contained movement. The difference in the active navigation condition was not significant. Thus, active navigation supported the route navigation ability of participants who observed movement to perform on the same level as participants who controlled movement. Performance in the no-navigation condition was surprisingly good for both movement control conditions. We speculate that participants in the no-navigation condition used a landmark-based approach in the route navigation task (as indicated by their superior landmark recognition) rather than a map-based approach as in the other navigation conditions. Apparently, this strategy was sufficient for identifying an efficient route also after observed movement.

Taken together, these findings imply that active navigation control with map-based instruction can compensate for active movement control, as indicated by comparable (route navigation task) or even better (tour-integration task) spatial learning after observed movement compared to self-contained movement. However, navigation with maps also distracted from the encoding of landmark knowledge, in line with findings on goal specificity (e.g., Taylor et al., 1999), and may thus be a disadvantageous factor for route navigation when a landmark-based strategy is possible.

General discussion

The aim of the present research was to clarify whether self-contained movement leads to a genuine route learning advantage in virtual environments, and whether such an advantage is further supported or inhibited by other factors that can been considered equally relevant in active navigation; namely learning intention (Experiment 1), instruction control and instruction specificity (Experiment 2), and navigation control (Experiment 3). In all three 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, one of the participants was responsible for navigation with verbal route descriptions (Experiment 2) or with fragmented maps (Experiment 3). In sum, the robust results across experiments suggest that self-contained movement provides a genuine advantage for the encoding of landmark knowledge as compared to observed movement. A manipulation of learning intention in Experiment 1 showed few if any results, and it did not affect the differences in spatial learning between the self-contained and observed movement condition. We conclude that learning intention is of minor relevance in active navigation. However, instruction control, instruction specificity (both Experiment 2) and navigation control (Experiment 3) were critical for the development of route knowledge (i.e., the ability to reconstruct the route on an incomplete map and to navigate the route again), and determined the advantage of self-contained as compared to observed movement. Regarding survey knowledge, Experiment 1 confirmed findings from previous studies that genuine survey knowledge tasks are rather insensitive to manipulations of active navigation. These findings are discussed in detail below.

We found consistently superior landmark knowledge after self-contained as compared to observed movement in congruence with some previous studies (Fenech et al., 2010; Hahm et al., 2007), whereas a number of studies on landmark knowledge in virtual environments did not report such an effect (e.g., 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, inconsistent with this explanation, the landmark knowledge advantage also appeared in Experiment 3, where the landmarks were not explicitly mentioned. Alternatively, it could be argued that the fixed field of vision in the present experiments may have added to the advantage of the self-contained movement condition: In contrast to an actual driver/passenger situation, participants in the observed movement condition were not free to look around, thus not being able to perceive and encode landmark information at their own pace. A study from our lab on active navigation in a real environment indicates that this explanation does not hold true: we also found a landmark knowledge advantage of drivers over back-seat drivers on a tandem-bike in one of two experiments (von Stülpnagel & Steffens, 2012). Taken together, despite the inconsistent findings in previous research, our findings were consistent and resistant against all manipulations, and thus speak in favor of a genuine advantage of self-contained movement for the encoding of landmark knowledge.

Experiments 2–3 imply that in contrast to landmark knowledge, route knowledge (as indicated by the ability to reconstruct the outline of the route in the tour-integration task and to repeat it in the route navigation task) 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 instructions that either consisted of landmark information only or additional layout information. An advantage of self-contained movement over observed movement in tour-integration depended on the additional layout information, and an advantage in route navigation on instruction control. Without these prerequisites, 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 using fragmented maps. Active navigation enabled participants who observed movement to outperform participants who controlled movement in the tour-integration task. More importantly, active navigation also enabled participants who observed movement to compensate for otherwise consistent disadvantages in route navigation performance. In sum, whereas information control and additional layout information increased the difference in route knowledge between self-contained and observed movement in Experiment 2, active navigation 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 (see Craik & Lockhart, 1972; Lockhart & Craik, 1980). 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 (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 was different in Experiment 3, where the transfer of 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 navigation rather than movement control determined the development of route 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.

The present research aimed to disentangle the effects relevant in active navigation for a specific route rather than for an environment in general and the development of a cognitive map. However, Experiment 1 yielded further evidence that self-contained movement does not enable better performance in genuine survey knowledge tasks such as landmark pointing and map-sketching than observed movement, which is in line with previous research (Wallet, et al., 2008). Given the overall poor performances in these tasks, these null-findings are likely a result of task difficulty. We hypothesize that virtual environments represent rather impoverished images of reality (Witmer, et al., 1996), despite many similarities of virtual and real environments regarding spatial learning (e.g., Ruddle, et al., 1997; Waller, 2000). Moving in virtual environments is also not a familiar activity for most people. Thus, complex virtual environments may be too alien and their depiction too abstract to most people to enable a rapid development of a mental map as required for survey knowledge tasks.

Some aspects of the research at hand deserve further discussion. A closer examination of the route navigation results reveals a contrast between Experiments 1 and 2. More specifically, all participants listened to the navigational instructions presented automatically in Experiment 1, and a route navigation advantage of self-contained over observed movement emerged. Thus, in Experiment 2 one should expect a comparable effect in the listening condition, where the participants received the navigational instructions from their partner. However, we found no route navigation advantage of self-contained as compared to observed movement in Experiment 2 (which was limited to participants who controlled movement and *gave* instructions.) We can only speculate about the reasons for this difference. It is possible that the automatic presentation of navigation instructions in Experiment 1 differed qualitatively from the oral presentation in Experiment 2. For example, we cannot exclude that the oral propagation of instructions was in some cases accompanied by pointing gestures.

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 insights 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 further potential concern regards the change from a verbal to a pictorial instruction format in Experiment 3. It can be argued that keeping the instruction format constant and realizing active navigation control by allowing a free exploration of an environment would have been the more appropriate approach, because the implemented changes may have differently affected the experimental conditions. However, in order to keep our research consistent in its aim to disentangle the effects relevant in active navigation *for a specific route* (rather than for an environment in general), this change was necessary. Even if verbal route instructions as compared to pictorial route instructions represent a major change in procedure, this does not compromise our conclusion that self-contained movement does not lead to superior encoding of route knowledge per se, but that other factors (i.e., instruction specificity and navigation control) are crucial to this advantage.

Finally, the research at hand manipulated movement control as a central factor, ajar to driver/passenger situations. However, we have 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.

Conclusion

The present findings provide evidence that self-contained movement (similar as driving a vehicle) in complex virtual environments leads to a genuine advantage in landmark knowledge as compared to observed movement (similar to being a passenger, Experiments 1–3). In contrast, we found no effects of movement control on survey knowledge (Experiment 1). However, the development of route knowledge depended on the availability of instruction control (Experiment 2) and active navigation control (Experiment 3)—factors that are frequently, but not necessarily, entangled with self-contained movement. A route 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 spatial information is mandatory also to people who observe movement, they are not disadvantaged in route learning as compared to people who control movement.

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Appendix

Experiment 1

There is evidence for gender differences in spatial abilities and orientation strategies, with men performing better than women (Iachini, Ruotolo, & Ruggiero, 2009; Lawton, 1994; Pazzaglia & De Beni, 2001, but see Rossano & Reardon, 1999). A meta-analysis showed that gender differences are found only in about 50 % of studies on spatial abilities (Coluccia & Louse, 2004). We checked for potential confounds of participants gender with separate one-way (female vs. male) ANOVAs for the self-reports of sense of orientation and computer game experience, as well as all dependent variables. Women ($M = 2.77$, $SD = 0.18$) rated their sense of orientation lower than men ($M = 3.41$, $SD = 0.18$), $F(1,79) = 6.48$, $p < 0.02$, $\eta_p^2 = 0.08$. Women ($M = 1.95$, $SD = 0.21$) also reported less computer game experience than men ($M = 3.09$, $SD = 0.20$), $F(1,81) = 15.72$, $p < 0.001$, $\eta_p^2 = 0.16$. These differences did not affect the dependent variables in general, as there were no gender differences for number of hits, pointing accuracy, and path-sketching, all Fs < 3.61, ns. However, women ($M = .10$, $SD = 0.11$) made more false alarms than men ($M = 0.05$, $SD = 0.07$), $F(1,77) = 4.45$, $p < 0.01$, $\eta_p^2 = 0.06$. Additionally, men ($M = 94$ s, $SD = 39$) were faster in the route navigation task than women ($M = 126$ s, $SD = 55$), $F(1,76) = 6.19$, $p < 0.001$, $\eta_p^2 = 0.08$. Gender differences were not the primary focus of the present research, and we thus refrain from further interpretations of these effects.

Table 4 Statistical data of all covariates, separately presented for the respective dependent variables and experiments

Dependent variable	Covariate	F value, p value, effect size (η^2)
Experiment 1		
False alarms	Sense of orientation	$F(1,75) = 4.63$, $p < 0.04$, $\eta_p^2 = 0.06$
Hits	Computer game experience	$F(1,78) = 5.49$, $p < 0.03$, $\eta_p^2 = 0.07$
Route navigation	Sense of orientation	$F(1,74) = 4.86$, $p < 0.04$, $\eta_p^2 = 0.06$
	Computer game experience	$F(1,74) = 4.57$, $p < 0.04$, $\eta_p^2 = 0.06$
Experiment 2		
Route navigation	Computer game experience	$F(1,79) = 11.20$, $p = 0.001$, $\eta_p^2 = 0.12$
Experiment 3		
Route navigation	Computer game experience	$F(1,94) = 12.82$, $p = 0.001$, $\eta_p^2 = 0.12$

$p < 0.05$ for all reported covariates

An exploratory inclusion of participant gender as an additional factor did not change the result patterns. Consequently, we abandoned a balanced proportion of participant gender in the Experiments 2–3, and distributed male participants around equally over the experimental conditions.

We also 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, ns. A correlation analysis of these items with all dependent variables (landmark recognition hits and false alarms, pointing accuracy, path-sketching performance, and route navigation performance) revealed significant correlations of general sense of orientation with the number of recognition false alarms ($r = 0.24$, $p = 0.03$) and with route navigation performance ($r = 0.28$, $p = 0.01$), as well as significant correlations of computer game experience with the number of recognition hits ($r = 0.24$, $p = 0.03$) and with route navigation performance ($r = 0.27$, $p = 0.02$). 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. Statistical data regarding the covariates of this and all following experiments are reported in Table 4.

Experiment 2

As a 2 (movement control) × 2 (instruction control) × 2 (instruction specificity) ANOVA showed, computer game experience ($M = 1.18$, SD = 0.92) did not differ between the experimental groups, all Fs < 2.83, ns. A correlation analysis of computer game experience with all dependent variables (landmark recognition hits and false alarms, tour-integration performance, and route navigation performance) revealed a significant correlation of computer game experience with route navigation performance ($r = 0.32$, $p < 0.01$). We included computer game experience as a covariate in the respective analysis after confirming that all assumptions held, see Table 4.

Experiment 3

Computer game experience ($M = 2.15$, SD = 0.97) did not differ between the experimental groups, as a 2 (movement control) × 3 (navigation control) ANOVA showed (all Fs < 1). A correlation analysis of computer game experience with all dependent variables revealed a significant correlation of computer game experience with route navigation performance ($r = 0.26$, $p < 0.01$). We included computer game experience as a covariate in the respective analysis after confirming that all assumptions held, see Table 4.

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