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Is Route Learning More Than Serial Learning?

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Abstract: The nature of route learning in terms of the memorizing of landmarks was investigated. In Experiment 1, participants memorized landmarks while being guided through a computer-simulated hallway (dynamic, with spatial context), or while viewing the landmarks one by one in front of a black background (static, without context). Two more conditions completed the 2×2 design. One condition preserved the dynamic landmark viewing properties (observers approached each object, passed it, turned to the next object, and so on), but the background was black (dynamic, without context). In the other condition the observer saw a stationary display of each object within a hallway, but did not approach the object (static, with context). Serial recall was much better after viewing the landmarks in the dynamic presentation format with spatial context than in the other conditions. Experiment 2 showed that the superior performance in the dynamic condition with context was abolished when all hallway segments were equally long. This implies that metric information is a component of route knowledge at a very early stage, which is incompatible with the dominant framework, but is compatible with the alternative framework for spatial microgenesis.

Keywords: route learning, serial learning, spatial knowledge, serial recall

1. INTRODUCTION

A prominent theoretical framework in spatial cognition research is that of Siegel and White (1975). They assumed that spatial knowledge develops from an initial stage of landmark knowledge to an intermediate stage of route knowledge to the final stage of survey knowledge (see also Golledge, 1987; Thorndyke, 1981). In this framework, landmark knowledge is defined as the knowledge of the identities and positions of landmarks. The definitions

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of landmarks cover visual objects which are perceived and remembered due to their strategic function (Lynch, 1960), their shape and structure (Presson & Montello, 1988), or due to their sociocultural significance (Appleyard, 1969), their significance as reference points (Sadalla, Burroughs, & Staplin, 1980) or as prototype locations (Newcombe & Huttenlocher, 2000). Route knowledge in this framework is defined as the knowledge of the order of these landmarks: "If one knows at the beginning of a 'journey' that one is going to see a particular landmark (or an ordered sequence of landmarks), one *has* a route" (Siegel & White, 1975, p. 24). Finally, survey knowledge is given by a two-dimensional scaled representation of the layout, much like a map. Although this "dominant framework" (Montello, 1998) has been criticized as imprecise (Blades, 1991) and an alternative "continuous" framework for spatial microgenesis (Ishikawa & Montello, 2006; Montello, 1998) has been suggested in its place, central notions such as landmark knowledge, route knowledge, and survey knowledge continue to remain important in the area of spatial cognition.

Within the dominant framework and its variants, a large number of studies have been conducted to assess the organization of spatial knowledge, but mostly with regard to survey knowledge. For instance, there is by now ample evidence that survey knowledge is hierarchically organized (McNamara, 1986; McNamara, Hardy, & Hirtle, 1989; McNamara & LeSueur, 1989; McNamara, Ratcliff, & McKoon, 1984). In contrast, route knowledge does not seem to have been investigated in this detail (e.g., Lee, Tappe, & Klippel, 2002). This could be so because the acquisition of route knowledge is implicitly regarded as one of many instances of standard, list-type serial learning about which a great deal has already been known for quite some time from human (Crowder & Greene, 2000) and animal studies (Compton, 1991). If this was so, then the acquisition of knowledge about the order of landmarks should be based exclusively on the forming of direct and remote associations between ordinal positions and landmarks (Johnson, 1991) and/or on direct and remote landmark-landmark associations (Crowder & Greene, 2000) just as classical list-type serial learning is assumed to be based in the forming of such associations. In fact, Siegel and White (1975) thought it possible that route learning could be conceived of as "a kind of serial learning" (p. 28) of sequences of decisions (generally about changes in heading) or, more likely, of associations between landmarks and changes in bearing. If route learning was in fact just serial learning, then it should not matter whether sequences of objects are learned from a list of successively presented objects or whether they are learned as landmarks along a route under otherwise identical conditions (e.g., identical exposure time, instruction to memorize, physical characteristics such as size, etc.).

While this seems to be a straightforward and reasonable position, there are two obvious surface features with respect to which route learning tasks differ from typical serial learning tasks. First, objects (i.e., the landmarks) are presented in a dynamic presentation format in that the observer approaches the objects and passes them, rather than *static* as in standard, list-type serial learning situations. Second, objects are presented in a spatial *context* rather than in list form in front of a homogenous background, that is, *without context*. These features, either in isolation or combined, might affect the learning processes involved, as a consequence of which route learning may differ from learning lists of objects. For instance, these additional features may stimulate additional processes involved in the learning of landmark sequences, which, in turn, might lead to better memory for the serial positions of landmarks than for the serial positions of objects in a standard, list-type serial learning procedure.

The purpose of Experiment 1 was to clarify, at an empirical level, whether the learning of a series of objects benefits if the objects are presented as landmarks in a simple simulated spatial scenario rather than in a more classical list-type serial situation. More precisely, we implemented four conditions that resulted from a manipulation of the two variables mentioned in the previous paragraph. In the *dynamic-with-context condition*, landmarks were presented within a simulated spatial scenario that is typical for route learning experiments in our lab (Jansen-Osmann, 2002; Jansen-Osmann & Wiedenbauer, 2004b; Wiedenbauer & Jansen-Osmann, 2006). The observer approached an object in a simulated hallway, passed it, turned left or right, and then the next object came into view. The *dynamic-without-context* condition preserved the dynamic viewing properties of the landmarks (the observer approached each object implying an expansion of the visual angle occupied by the object, passed the object, turned to the next to-be-approached object, and so on), but the background was homogeneously black. In the *static-with-context condition*, the observer saw a stationary display of each object within the hallway that served as the spatial scenario, but did not approach the object. The landmarks were visible for the same amount of time for which the landmarks were in view in the two dynamic conditions. After this interval, the display switched such that the next object came into view. Finally, in the *static-without-context condition*, the landmarks were presented as stationary objects but in front of a homogeneously black background. The latter condition was thought to approximate a standard, "context-free" and list-type serial learning situation.

If the acquisition of route knowledge in terms of the order of landmarks were just another instance of standard, list-type serial learning, then the forming of associations among ordinal positions and items should be the sole determinants of performance and, thus, there should be no differences between the static-without-context condition (list-type serial learning) on the one side and the dynamic-with-context condition (route learning) on the other. In contrast, such a difference should be observed if route learning was in some sense more efficient than list-type serial leaning.

In case of a difference between list-type serial learning and route learning the remaining two conditions may help us to decide whether the dynamic presentation format, the spatial context, or a combination of these affected the learning processes involved. For instance, one might expect that the dynamic presentation format that is characteristic of route learning improves serial recall of landmarks because the sequentiality of the landmarks is more prominent if the objects are presented dynamically than if they are presented as static objects, one after the other. The dynamic presentation format provides continuous distance-to-landmark information via visual angle expansion from which time-to-collision information can be computed (cf. Laurent & Gabbiani, 1998). It also contains smooth transitions between the views of two successive landmarks. This might facilitate the forming of interactive images, thus enhancing the learning processes involved (Bower, 1970; Bower & Winzenz, 1970).

The presence of a spatial context alone may also enhance serial recall. For instance, when viewed from the beginning of a hallway segment, the objects differ in how far away they appear from the observer (as conveyed by texture gradient, linear perspective, and size of the object at the end of the segment) depending on the length of the segment in which they are placed. This additional information may help distinguishing landmarks from each other by adding information that makes them more distinct at retrieval (Schmidt, 1991). Finally, both variables together may be important in that only their combination can provide the cues available during normal route learning that enable superior learning of a sequence of landmarks.

2. EXPERIMENT 1

2.1. Method

2.1.1. Participants. Participants were 168 Heinrich-Heine-University students (91 women) who were recruited on campus. Their age ranged from 19 to 53 years ($M = 24$). All participants were tested individually and were randomly assigned to one of the four cells defined by the 2×2 design of the experiment (see below). Within each cell, it was randomly decided whether participants received Landmark Set 1 or 2 (see section 2.1.2).

2.1.2. Apparatus and Materials. The experimental scenario was presented on a 17-inch TFT screen controlled by a Pentium 4 (2.0 GHz) PC via an nVidia GeForce 4 graphics card. The scenario was a hallway created using *3D Game Studio A5*. Viewing distance was approximately 50 cm, simulated field of view was 65°.

In the dynamic-with-context condition, participants experienced a series of nine landmarks in a winding, multi-segment hallway with stonewalls, a green floor, and an open ceiling so that the sky was visible (see Figure 1). The hallway consisted of ten segments that differed in length and, hence, in viewing times of the landmarks as well as in how long it took to travel from the beginning of a segment to the end. The landmarks were placed

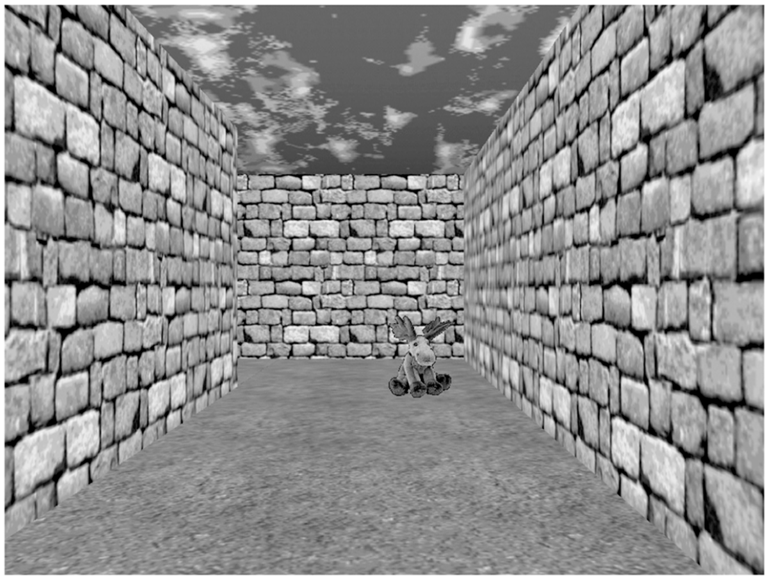

Figure 1. Exemplary view of an object (the moose) in the hallway.

near the end of the segments except for the first segment, which was empty (see Figure 2a). The observer appeared to approach a particular landmark in a constant speed, passed it, and then turned to the left or to the right (depending on how the hallway would continue) such that the next object near the end of the subsequent segment would come into view. The landmarks can thus be classified as local landmarks (Steck & Mallot, 2000).

This type of scenario has been used successfully several times before in our lab (see e.g., Jansen-Osmann, 2002; Jansen-Osmann & Wiedenbauer, 2004b; Wiedenbauer & Jansen-Osmann, 2006). The dynamic-without-context condition was exactly the same, with the exception that the walls, the floor, and the sky were replaced by black surfaces such that the landmarks appeared as isolated objects within an otherwise homogeneously black environment which the observer approached and then passed, followed by a turn towards the next object. In the static-with-context condition, participants saw each landmark from the beginning of each segment of the hallway, but they did not approach it. Each view was presented for the same amount of time for which the particular landmark was visible in the dynamic conditions (except that the object was presented completely for the first and final fractions of a second during which the object appeared partially occluded in the dynamic conditions when coming into view as the observer circled around a corner in the virtual hallway). The static-without-context condition was the same with the exception that the landmarks were presented in front of a black background at the center of the screen.

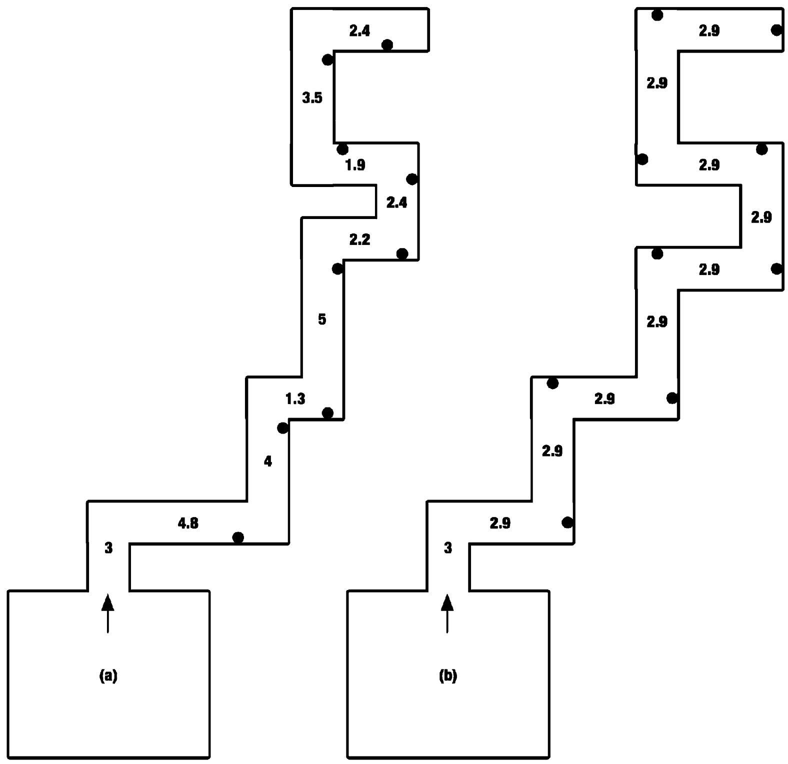

Figure 2. Bird-eye's view of the hallways used in Experiments 1 (a) and 2 (b). Numbers represent how long objects were in view (in seconds).

The landmarks were stuffed animals that had already been used successfully as landmarks in prior studies from our lab (Jansen-Osmann, 2002; Jansen-Osmann & Wiedenbauer, 2004b; Wiedenbauer & Jansen-Osmann, 2006). The landmarks were assigned to one of two sets, and to fixed serial positions within each set (Set 1: 1. moose, 2. lion, 3. rabbit, 4. chimpanzee, 5. lamb, 6. duck, 7. elephant, 8. wolf, 9. fox; Set 2: 1. seal, 2. hare, 3. dog, 4. dolphin, 5. donkey, 6. crocodile, 7. tiger, 8. pelican, 9. bear). Participants were randomly assigned to either Set 1 or 2. Landmarks were assigned to fixed serial positions for economical reasons and also because the associated penalty of not being able to interpret serial position curves was negligible given that we were not interested in serial position curves anyway but only in global performance differences among conditions.

2.1.3. Procedure. Individual test sessions lasted about 10 minutes. Participants were told that they would have to remember objects presented on the computer screen, but they were not given any specific information as to the type of memory test to expect. Next they watched the sequence of objects presented in dynamic or static format and with or without context, depending on the condition to which they had been assigned (i.e., participants were guided through the scenario and did not actively navigate). Immediately after the final object, participants were asked to recall the objects in the order in which they had just been presented, and also to indicate when they were not able to recall the object associated with a particular ordinal position. Recall was recorded for later evaluation by the experimenter.

2.1.4. Design. The main independent variables were presentation format (dynamic vs. static) and context (with vs. without context). The dependent variable was serial recall, that is, the frequency with which the objects were recalled at the serial positions at which they had been presented. Several different verbal labels for the same object were accepted as correct as long as they seemed to be plausible. For instance, sheep was accepted as an alternative to lamb, and goose was accepted as an alternative to pelican.

Our goal was to detect effects between individual cells of our experimental design, primarily between the dynamic-with-context (route learning) and the static-without-context conditions (list-type serial learning). We wanted to be able to detect such effects if they were at least "large" according to the conventions introduced by Cohen (1977), that is, we assumed $f = 0.4$ (which corresponds to $\eta^2 = .14$) as the size of the to-be-detected performance difference given $\alpha = \beta = .05$. An a priori power analysis suggested that a total sample size of $N = 168$ (42 participants in each of the cells defined by the 2×2 design) was needed (Faul, Erdfelder, Lang, & Buchner, 2007). With this sample size, $f = 0.4$ as the assumed effect size, and $\alpha = .05$, the power of tests of the presentation format and context main effects and their interaction would be as large as $1 - \beta = .99$. The level of α was set to .05, except for post-hoc comparisons of individual cells in the design for which the significance level was Bonferoni-Holm corrected (Holm, 1979).

2.1.5. Results. There was no main effect of the landmark set (Set 1 or Set 2; see Apparatus and Materials). This variable also did not interact with any of the independent variables of the design. For brevity we therefore omitted this variable from the analyses that are reported. This did not change any of the statistical conclusions about the effects and interactions of the remaining variables.

The upper panel of Figure 3 illustrates that serial recall of landmarks in the dynamic condition with spatial context was clearly better than serial recall in all other conditions. An ANOVA with presentation format (dynamic vs. static) and context (with vs. without) as between-subjects variables showed statistically significant main effects of presentation format, $F(1,164) = 4.73$, $p < .05$, $\eta^2 = .03$, of context, $F(1,164) = 9.87$, $p < .01$, $\eta^2 = .06$, and a statistically significant interaction between presentation format and context,

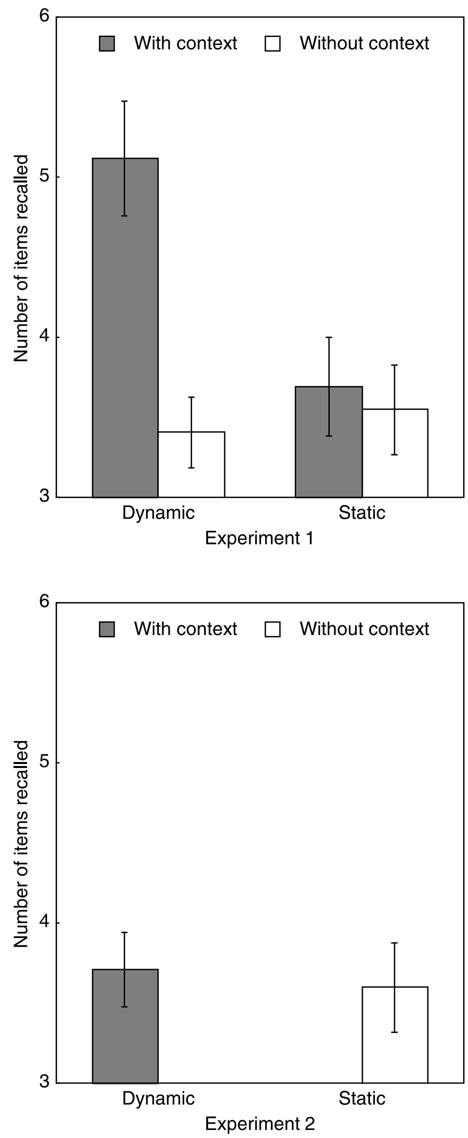

Figure 3. *Upper panel:* Average number of objects recalled correctly at their serial positions (nine objects at most) in Experiment 1 as a function of presentation format and context. Error bars represent the standard errors of the means. *Lower Panel:* Average number of objects recalled correctly at their serial positions (nine objects at most) in Experiment 2 as a function of presentation format and context. Error bars represent the standard errors of the means.

$F(1,164) = 7.07$, $p < .01$, $\eta^2 = .04$. Participants in the dynamic-with-context condition remembered more landmarks at their correct serial positions (57%) than participants in the dynamic-without-context condition (38%), the static-with-context condition (41%), and the static-without-context condition (40%). Separate analyses showed that, first, the dynamic-with-context (route learning) condition differed significantly from the static-without-context (list-type serial learning) condition, $F(1,82) = 11.99$, $p < .01$, $\eta^2 = .13$, but also from the static-with-context condition, $F(1,82) = 9.17$, $p < .01$, $\eta^2 = .10$, and the dynamic-without-context condition, $F(1,82) = 16.40$, $p < .01$, $\eta^2 = .17$. In contrast, the two static conditions did not differ from each other, $F(1,82) = 0.12$, $p = .73$, $\eta^2 < .01$. Also, the two no-context conditions did not differ as a function of the presentation format manipulation, $F(1,82) = 0.16$, $p = .69$, $\eta^2 < .01$.

2.1.6. Discussion. Serial recall performance was better in the dynamic-with-context (route learning) condition than in all other conditions. Note that this performance difference was huge in terms of raw performance scores. Participants in the dynamic-with-context condition on average recalled about 50% more landmarks at their correct positions than participants in the other conditions. This indicates that the acquisition of route knowledge in terms of the order of landmarks may not be just another instance of ordinary list-type serial learning.

Experiment 1 also showed that neither the dynamic presentation format nor the spatial context per se lead to improved serial recall performance. We had thought it possible that the dynamic presentation format alone could increase serial recall performance by facilitating the forming of interactive images at encoding. This hypothesis must be rejected. We also assumed that the spatial context alone might support serial recall in that the different lengths of the hallway segments in which the landmarks were placed could be considered a feature that was added to the landmarks, making them more distinct at retrieval which could improve the recall of the serial order of the objects. This hypothesis, too, must be rejected.

Given that neither the dynamic presentation format nor the spatial context in isolation but only their combination must have provided the information that enabled superior learning of a sequence of landmarks, the next step necessarily was to determine more precisely what this information could be. An important difference between the dynamic-with-context condition and all other conditions was in the cues to the spatial properties of the experimental situation. More precisely, only the dynamic-with-context condition provided cues to the coherent spatial layout in which the objects were placed. If the landmarks were associated with places in the layout, then they would be integrated in a coherent representation, and the succession of hallway segments of different lengths could serve to structure the otherwise homogeneous learning context and thus enable the forming of clusters of objects much like the rhythm of presentation enables the clustering of sequences of digits (Bower & Winzenz, 1969), thereby enhancing serial recall performance.

At first sight, this assumption is somewhat similar to our original hypothesis about the effects of the spatial context alone. The important difference is that distance information in the static-with-context condition was discontinuous as in a slide show such that it could not serve as a good cue to the spatial layout in which the objects were placed. In addition, information about the segment length was available only in terms of a static cue, that is, in terms of the viewing distance from the beginning of the segment. In contrast, the dynamic-with-context condition provided additional dynamic visual (e.g., optical flow, time-to-collision information) and temporal (travel duration) cues to segment length, making it more likely that segment length information can be extracted and retained. A further, albeit speculative, consideration is that humans just like many animal species may be particularly good at processing information about the geometric shape of the environment because they are equipped with a special "cognitive module" for extracting information about the geometric frame of the environment around them (Cheng & Newcombe, 2005) or because they are equipped with a core knowledge system for places in the spatial layout and their geometrical relationship (Spelke & Kinzler, 2007).

Features of the environment such as landmarks could then be associated with (or "glued" on, cf. Cheng & Newcombe, 2005) the geometrical layouts in which they were experienced, as a consequence of which the landmarks may become more readily available when the geometrical layout is retrieved. If such a module existed, and if this module could be assumed to provide additional processing resources for the storage and retrieval of geometrical information, then it seems reasonable to assume that it is involved in learning and retrieval to the degree to which the learning environment contains the relevant spatial cues. Of the conditions used in Experiment 1, the dynamic-with-context condition provided the largest number of cues to a spatial environment.

From these considerations it can be deduced that if the landmarks were indeed associated with places in the layout in which the succession of dynamically experienced hallway segments of different lengths structure the otherwise homogeneous learning context, then the performance difference between the dynamic-with-context (route learning) and the static-without-context (list-type serial learning) conditions should disappear when all hallway segments are changed to have the same length. In addition, performance in the dynamic-with-context condition should be lower in this situation than it was in this particular condition in Experiment 1, whereas performance in the static-without-context condition should be similar to the performance level observed in this particular condition in Experiment 1. Given that performance in the remaining two conditions used in Experiment 1 (static-with-context and dynamic-without-context) was basically the same as that in the static-without-context condition, no new insights were to be expected from including these conditions in Experiment 2, which is why they were not included.

Note that the preceding assumptions about the importance of hallway segment lengths are clearly incompatible with the dominant framework, according to which route learning begins with the learning of the succession of landmarks and their associated changes in bearings. At least initially in route learning (and, thus, in the situation that is given in the present experiments), information between landmarks is irrelevant (Siegel & White, 1975, p. 29). Importantly, this implies that metric information about hallway segments of different lengths cannot be part of the knowledge of the route. Metric information comes into play only at the level of survey knowledge, which comes last and builds on route knowledge.

The situation is completely different for the alternative framework for spatial microgenesis presented by Montello (1998). In this framework the idea is rejected that there could ever be a stage at which only route knowledge exists which does not contain metric information about distance. Quite to the contrary, "metric configurational knowledge begins to be acquired on first exposure to a novel place" (Montello, 1998, p. 146).

In essence, then, should the performance difference between the dynamic-with-context (route learning) and the static-without-context (list-type serial learning) conditions disappear with equal-length hallway segments, then this would be evidence against the dominant framework, whereas this finding would support Montello's (1998) alternative framework for spatial microgenesis.

3. EXPERIMENT 2

3.1. Method

Participants were 124 Heinrich-Heine-University students (62 women) who were recruited on campus. Their age ranged from 18 to 47 years ($M = 24$). All participants were tested individually and were randomly assigned to one of the two experimental groups. None of them had participated in Experiment 1.

3.1.1. Apparatus, Materials and Procedure. Apparatus, materials, and procedure were identical to those of Experiment 1 with the following exceptions. The spatial layout of the hallway underlying the dynamic-with-context condition was changed such that all ten segments had the same length and the overall length was similar to that of the hallway used in Experiment 1 (see Figure 2b). As a consequence, the presentation times for objects in the static-without-context condition were identical for all objects and the same as the durations for which objects in the dynamic condition were in full view. To simplify things, only Set 1 of the landmarks was used. This seemed justified given that there was no effect of landmark set in Experiment 1.

3.1.2. Design. The main independent variable was presentation format (dynamic with context, static without context). The dependent variable was serial recall as in Experiment 1.

The size of the difference between the dynamic-with-context and the static-without-context condition in Experiment 1 was $\eta^2 = .13$ which corresponds to $f = 0.39$ and thus was quite close to the "large" effect ($f = 0.4$) we had planned for. In order to be on the safe side, we decided to base our sample size calculation for Experiment 2 on the more conservative assumption of a population effect size of $\eta^2 = .10$ which corresponds to about $f = 0.33$. An a priori power analysis suggested that given $\alpha = \beta = .05$, a total sample size of $N = 122$ (61 participants in each condition) was needed. We were able to recruit 124 participants so that the power was even slightly higher than $1 - \beta = .95$.

3.1.3. Results. The lower panel of Figure 3 illustrates the results. An ANOVA showed no effect of presentation format, $F(1,122) = .10$, $p = .76$, $\eta^2 < .01$. Participants in the dynamic-with-context condition remembered just as many landmarks (41%) as participants in the dynamic-without context condition (40%). What is more, the level of performance in the dynamic-with-context condition was considerably lower than in the corresponding condition in Experiment 1. Both groups in this experiment were at the level of the three low-performance groups in Experiment 1 at a descriptive level, and a direct comparison of the data from both experiments (with $N = 126$ for all groups but the dynamic-with-context group in Experiment 1 combined and $N = 124$ for both groups of Experiment 2 combined) confirmed that there was no such difference, $F(1,248) = 0.19$, $p = .66$, $\eta^2 < .01$.

3.1.4. Discussion. With all hallway segments restricted to the same length, there was no longer a performance advantage of the dynamic-with-context (route learning) over the static-without-context (list-type serial learning) condition. This suggests that features as nonobvious as the length of the segments associated with particular landmarks may help to structure a particular route such that the acquisition of landmark knowledge is improved considerably over a condition lacking this structure.

4. GENERAL DISCUSSION

The main purpose of the experiments presented here was to clarify, at an empirical level, whether the learning of a series of objects is better if the objects are presented as landmarks in a simple simulated spatial scenario than if the objects were presented in a classical list-type serial learning format.

Experiment 1 showed that the learning of a sequence of landmarks even in a simple simulated scenario is more than just another instance of list-type serial learning consisting of the forming of direct and remote associations between ordinal positions and landmarks and among landmarks (Crowder & Greene, 2000; Johnson, 1991). When the objects were experienced as part of a tour through a simulated spatial scenario, learning was greatly facilitated relative to conditions in which either the dynamic aspect of travelling along a path or the hallway context or both were missing. Interestingly, neither the spatial context nor the dynamic presentation format per se improved serial recall above the level shown in a condition in which all objects were presented in a purely list-type format. We thus had to reject our initial hypotheses that the dynamic presentation format might increase serial recall performance by facilitating the forming of interactive images at encoding, and that the spatial context might support serial recall in that the different lengths of the hallway segments could be considered a feature added to the landmarks, making the objects themselves more distinct at retrieval.

Experiment 2 showed that the serial recall advantage of the dynamic-with-context (route learning) over the static-without-context (list-type serial learning) condition disappeared when all hallway segments had the same length. In this situation, the hallway segments cannot any longer structure the otherwise homogeneous learning context. As a consequence, route learning really does become equivalent to serial learning. In other words, the metric structuring of the route strongly affected route knowledge acquisition. This fits with results reported by Allen (Allen, 1981; Allen & Kirasic, 1985) who showed that metric knowledge along a route, that is, distance knowledge is in turn influenced by the segmentation of the route.

The crucial role of hallway segments of different lengths in the present single-trial learning experiments implies that metric information must be a component of route knowledge that is acquired at a very early stage of learning about a spatial scenario. This implication is fully consistent with Montello's (1998) framework for spatial microgenesis which postulates, among other things, that metric configurational knowledge begins to be acquired as soon as one is exposed to a novel place. In contrast, the implication contradicts the dominant framework (Siegel & White, 1975) according to which information between landmarks is irrelevant at least during early stages of route learning.

Apart from these theoretical implications an important purpose of the present research was to elucidate whether the learning of a series of objects is better if the objects are presented as landmarks in a simple simulated spatial scenario than if they are presented in a classical list-type serial learning format. The former was indeed much better than the latter. We think of this as an interesting empirical phenomenon in its own right. In particular, it seems quite remarkable that a feature as subtle as the experienced hallway segment length can have such large effects on the serial learning of landmark objects. Recall that in Experiment 1, participants in the dynamic-with-context condition recalled about 50% more objects in their correct serial positions than participants in the other conditions. Then again, perhaps this is not as surprising as we thought, given that the simulated travel through the virtual hallway clearly provided quite a few distance cues, both in terms of static and dynamic visual distance cues and as well as in terms of travel duration information. Another possibility is that learning in this context benefits from particularly efficient learning processes such as those implied by the postulated core knowledge system for places in the spatial layout and their geometrical relationship (Spelke & Kinzler, 2007) or a special "cognitive module" for extracting information about the geometric frame of the surrounding environment (Cheng & Newcombe, 2005). While this may seem plausible given the contrast between the apparent subtlety of the information necessary for the serial recall advantage of the dynamic-with-context condition over the other conditions, the present data are only consistent with such a theoretical proposal; they do not in any strict way favor such a proposal over other possibilities.

At present we only know that differences in segment length were critical in the particular simulated scenario that we used. It is currently not clear whether the manipulation of other features that may help to structure the sequence of landmarks such as a different wall or floor colors for each segment of the hallway would have had similar effects (Jansen-Osmann & Wiedenbauer, 2004c). Also, the present results were obtained in a restricted virtual environmental situation, with specific advantages and disadvantages (for a discussion, see Jansen-Osmann, Schmid, & Heil, 2007). Even though we know from studies with adults that at least the most important properties of the spatial representations that underlie spatial behavior can indeed be analyzed in both real and virtual environments (Loomis, Blascovich, & Beall, 1999), and that testing in virtual and real environments leads to similar results (Tlauka, 2007), there is evidence that navigation processes seem to be impaired in virtual environments (Ruddle & Lessels, 2006), because body-based locomotion information is missing. Nevertheless, we are confident that the present results generalize to real-world scenarios just like other results obtained with similar simulated virtual environments have before (Jansen-Osmann & Wiedenbauer, 2004a, 2006; Schmelter, Jansen-Osmann, & Heil, in press). However, whether this really is the case is ultimately an empirical question and, as such, is beyond the scope of the present paper.

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