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Distance cognition in virtual environmental space: Further investigations to clarify the route-angularity effect

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Abstract Two experiments with 72 participants in total investigated the route-angularity effect. This effect is shown when a greater number of turns along a route increase the estimated length of this route. In this study it was shown that the route-angularity effect is likely to be a memory-based effect depending on task difficulty. The important factor seems to be how heavily memory is loaded during learning. The route-angularity effect even appears in intentional learning, when memory is loaded heavily. Under this learning condition participants know beforehand that they have to estimate distances. All experiments were conducted in a controlled virtual environment, which allows a reliable investigation of distance estimations in environmental space.

Introduction

The knowledge of distances determines our behavior in an environmental space or in a space of navigation (Tversky, 2003)—a space that cannot be perceived from a single vantage point—in everyday life. For example, with a maximum amount of distance knowledge we can determine whether we can reach a location within an acceptable amount of time. This "distance knowledge" allows people to save time and energy. But we know from personal experience that estimated distances do not always coincide with objective distances. This holds particularly true for memories of distances in environmental spaces, because these distances always have to be inferred. Environmental distances differ from vista distances, which can be perceived from one single vantage point. Furthermore, subjective distances are not always metric, for example, they are not necessarily symmetric (McNamara & Diwadkar, 1997).

A person's memory for distance can be distorted by numerous factors: Travel time, travel effort, structure of the route, and number and type of environmental features along the route (Montello, 1997). One of the most frequently discussed sources of environmental distance information in the literature has been the number of features perceived during travel and/or recalled at the time of estimation. One prominent hypothesis in this context is the feature-accumulation hypothesis according to which the whole route is estimated as being longer when more landmarks are visible or when more memorable landmarks exist (Sadalla & Magel, 1980; Sadalla & Staplin, 1980a, 1980b; Sadalla, Staplin, & Burroughs, 1979). In this sense landmarks are any kind of objects or structural elements in the environment that can be perceived during the exploration of the environment, such as intersections, turns, and signs. This feature-accumulation hypothesis is related to the so-called route-segmentation hypothesis, which describes the influence of hierarchical structuring of a route on route distance estimates. Routes are hierarchically structured into stretches, which contain one or more landmarks. Distances between landmarks in different stretches are over-estimated relative to distances between landmarks in the same stretch (Allen, 1981, 1988; Allen & Kirasic, 1985). The relation between feature-accumulation and route-segmentation has recently been shown (Jansen-Osmann, & Berendt, 2004).

Research on the route-angularity effect connects studies concerning feature-accumulation and route-segmentation. This effect is shown when a greater number of turns along a route increases the estimated length of this route. In this sense, a turn induces a segmentation of the whole route. The route-angularity effect was initially investigated by Sadalla and his colleagues. For instance, Sadalla and Magel (1980) showed that a route that enforced a change in direction more often—in this case seven right-angle turns—was estimated to be longer than a route of the same physical length containing only two right-angle turns. This result was independent of the

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time of walking (once vs. three times), the time needed to learn the route, the straight-line distances between origin and goal, and the number of turns being compared. However, the route-angularity effect, which was obtained on a complex level of spatial behavior—namely, a memory and learning level—parallels those in research on path integration, which is at a less complex level (Mallot, 1999). Path integration means the integration of the traveler's local translation and rotations to provide a current estimate of position and orientation within a larger spatial framework (Loomis, Klatzky, Golledge, & Philbeck, 1999). Performance in a path completion task worsened with the number of legs of the path to be explored (Klatzky, Loomis, Golledge, Cicenelli, Doherty, & Pellegrino, 1990).

Sadalla and Magel (1980) offered three possible explanations for the route-angularity effect: The storage hypothesis, the scaling hypothesis, and the effort hypothesis. The *storage hypothesis* is based on the information storage model proposed by Milgram (1973). A strongly segmented route contains more information, necessitates more information processing activity, and leads to a larger amount of stored information. This amount of information determines the distance's subjective size. The *scaling hypothesis* assumes that the psychophysical function for distance estimation is a power function with a positive exponent less than 1.0 (Wiest & Bell, 1985). This implies that the ratio of estimated distance to physical distance will be smaller for longer distances. Because longer segments are relatively underestimated compared with shorter segments, a route with more turns will be overestimated in comparison with a route with fewer turns. The third hypothesis is the *effort hypothesis*. Participants estimate the length of a walked route based on the effort expended by walking. Walking complex routes is assumed to be more laborious than walking less complex routes; this implies that a route with more turns, the more complex one, is estimated as being longer.

The route-angularity effect was not replicated in all studies. Herman, Norton, and Klein (1986) did not find the effect in experiments with 8-, 10-, and 12-year-old children. In each of the three experiments, the children had to explore two routes, differing in the number of turns (two vs. zero turns; one vs. four turns; two vs. eight turns). No effects of age group or number of turns were found. In all three experiments, the route with more turns was not overestimated in comparison with the route of equal length but with fewer turns. This existing discrepancy was investigated in a study of Jansen-Osmann and Wiedenbauer (2004). In the absence of a convincing developmental theory, the authors assumed that this finding could only be explained by the fact that environmental features were not controlled (apart from the turns) or by differences in the experimental design. Therefore, they conducted three experiments, two with 11-year-old children and one with adults, in a virtual environment in which all features were controlled. Their results showed the number of turns to be influential only when the children had to explore and estimate *two* routes of equal length, one with two and one with seven turns. In contrast to this, in a between-participant design, no route-angularity effect appeared in children or in adults. These results seem to show that the route-angularity effect depends on the kind of design. Only in a within-participants design did 11-year-old children and adults underestimate a route with less turns in comparison with a route of equal length with more turns. This proved to be a stable finding across at least three different measurement methods: Ratio-estimation technique, route-drawing technique, and reproduction technique (Jansen-Osmann & Berendt, 2002; Jansen-Osmann & Wiedenbauer, 2004).

The question to be investigated is why a within- but not a between-participant design seems to advance the appearance of the route-angularity effect. Two explanations are possible. First of all, assuming that the two routes differ only in the number of turns, a within-participant comparison implies relative judgments due to this number, while a between-participant comparison implies absolute judgments. Participants in a between-participant study would not be able to estimate one route relative to the other due to their number of turns. A second reason might be that in the within-participant design participants would have to encode and estimate more than one route, so that memory is loaded more heavily. For that, people would be uncertain concerning their estimation and rely on heuristics, like the counting of the number of turns (Montello, 1995, 1997). Assuming that all distance estimations are the result of processes constructing from one long-term memory representation of the route a working memory representation, this construction process might be disturbed. In the two experiments presented here, we would like to concentrate on the second assumption. For that, a within-participant experiment was carried out in which memory was not loaded very heavily. This was done by retrieving distance estimations immediately after exploring one route, and not after the encoding and storing of two routes (Experiment 1).

Experiment 1

Hypothesis

The aim of the first experiment was to investigate whether or not there is a route-angularity effect in a within-participant design when participants have to estimate the length of the explored route immediately after exploration.

Method

Participants

Forty adults volunteered in Experiment 1—20 men and 20 women (mean age: 24.35 years). They were recruited through a local advertisement at the Heinrich-Heine-University, Düsseldorf, where the experiment took place. The participants were randomly assigned to one of two groups (see below).

Materials

Three routes were simulated with the software 3DGame Studio on a Pentium 4 PC. A typical corridor of the routes is shown in Fig. 1.

The routes consisted of a set of corridors: Route A with two turns (40 units), Route B with seven turns of equal length (40 units), and a straight Route C which was half the length of Routes A and B (20 units). The survey views of the three routes resembled those of the original study by Sadalla and Magel (1980) and its replication in a virtual environment (Jansen-Osmann & Berendt, 2002; Jansen-Osmann & Wiedenbauer, 2004). They are shown in Fig. 2.

Participants were seated in front of a 17-inch monitor and were familiarized with the routes by active navigation with a joystick. In the following test phase, participants received a protocol sheet, which contained a horizontal line. On this line, the length of Route C was marked with start-point X and goal-point Y, and was about one third of the total length of the line.

Procedure

Participants were tested individually in a single session, which lasted approximately 15 min. First of all, participants had to familiarize themselves with the use of a joystick or if they were already used to it with the special joystick's rotation and translation settings. The skill of using the joystick was taught in another (non-experimental) virtual world, which consisted of narrow virtual floors. When participants could easily manage the navigation procedure, the experiment started. They were instructed to explore the three routes, the exploration of Routes A and B being followed by that of Route C. To control velocity, it was requested that they push the joystick as far as possible, which resulted in the appropriate constantly moving speed. Furthermore, participants were not allowed to turn backwards or stop. The exploration order for the first experimental group was Route A-Route C-Route B-Route C (resulting in the following sequence: AACCBBCC) and for the second experimental group Route B-Route C-Route A-Route C (resulting in the following sequence: BBCCAACC). Because we did find an influence of the order of routes in children (Jansen-Osmann & Wiedenbauer, 2004), the order of the presentation was varied between groups. Every route had to be explored twice consecutively. After exploring Route C, distance estimations were retrieved by ratio-estimation. In this task, participants were asked to mark the length of Routes A and B in relation to Route C on a protocol sheet, starting from a point X. The millimeters of the marked route were measured. A single blank A4 sheet was used for every estimate. After estimating the distance of the first route (Route A or Route B) participants were told that they have also to estimate the distance of the next route and they were prompted on the spatial character of this task. The time needed to explore the routes was registered. We restrict the retrieval method to this ratio estimation task, because former studies showed that results on the route-angularity effect were stable across ratio-estimation, route-drawing, and virtual reproduction technique (Jansen-Osmann & Berendt, 2002).

Experimental design

There were two experimental factors: KIND OF ROUTE and ORDER OF ROUTE EXPLORATION. Factor

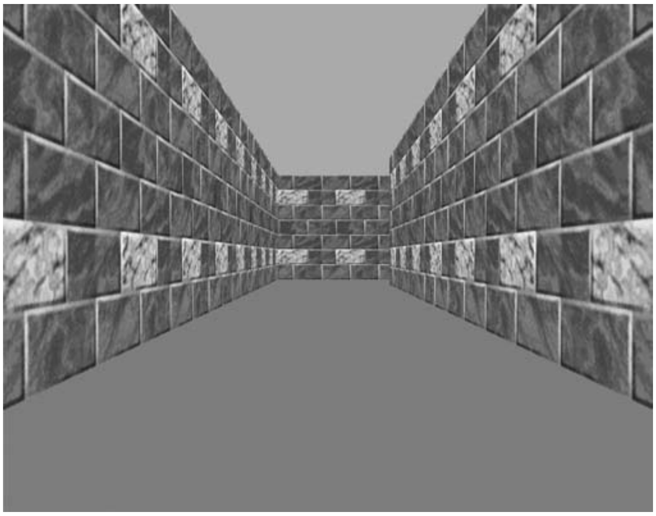

Fig. 1 An insight in one of the virtual routes of Experiment 1

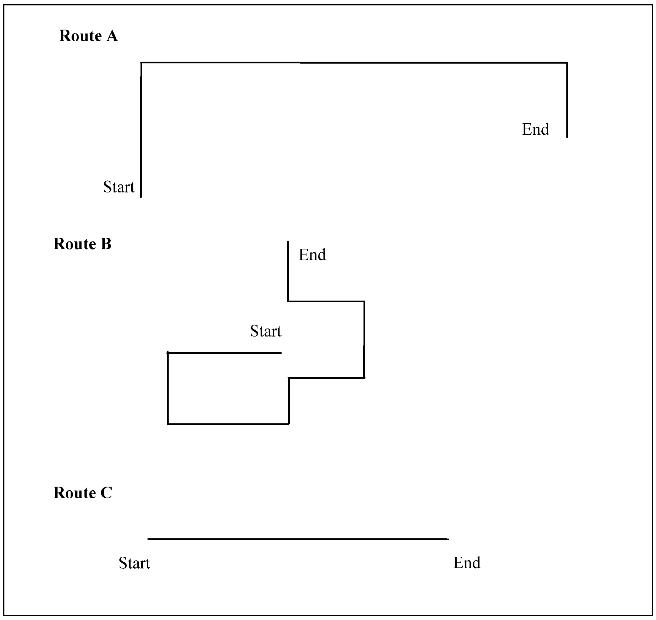

Fig. 2 Overview of the three routes of Experiment 1

KIND OF ROUTE was manipulated within participants (Route A with two turns; Route B with seven turns), factor ORDER OF ROUTE was a between-participant factor (exploration of Route A before B; exploration of Route B before A). There were two dependent variables:

1. Estimation of the route length via ratio-estimation (measured in millimeters)
2. Time needed to explore the routes (mreasured in seconds)

Results

Distance estimation

There was no significant influence of the factors KIND OF ROUTE, $F(1,38) = 1.04$, n.s., and ORDER OF ROUTE EXPLORATION, $F(1,38) = 0.8$, n.s., and no significant interaction between these two factors, $F(1,38) = 0.9$, n.s. Route A ($\bar{x} = 115$ mm, $s\bar{x} = 8.69$) with less turns was not underestimated in comparison with Route B with more turns ($\bar{x} = 109.45$ mm, $s\bar{x} = 7.79$). This was independent of their exploration order. Furthermore, comparing the second estimations between groups, Route A ($\bar{x} = 111.5$ mm, $s\bar{x} = 9.1$) was also not underestimated in comparison to Route B ($\bar{x} = 107.4$ mm, $s\bar{x} = 6.44$).

Exploration time

Time needed to explore Routes A and B differed significantly, $F(1,38) = 18.86$, $p < .001$. This was due to the different times needed by participants who explored Route B before Route A—a significant interaction between the factors KIND OF ROUTE and ORDER OF EXPLORATION, $F(1,38) = 9.98$, $p < .005$. In this condition, more time was needed to explore Route B ($\bar{x} = 45.17$ s, $s\bar{x} = 0.87$) than Route A ($\bar{x} = 42.07$ s, $s\bar{x} = 0.34$). At the beginning of the experiment it was more difficult to navigate through the narrow routes with seven turns.

Discussion

The results show that there is no route-angularity effect in a within-participant design when the estimation is retrieved immediately after the exploration of one route. That means that not the design per se but the task difficulty was important for the estimation. In other words, memory load might be a crucial factor accounting for the route-angularity effect.

Retrieving distance estimation immediately after exploring the route eased the task in comparison with the studies by Sadalla and Magel (1980) and Jansen-Osmann and Berendt (2002). Furthermore, participants knew before the exploration of the second route that they would have to estimate its distance. This result in an intentional learning condition is contrary to the incidental learning in the studies mentioned above (Jansen-Osmann & Berendt, 2002; Jansen-Osmann & Wiedenbauer, 2004). Because there was no influence of the exploration of the order of routes, we can assume that there is no route-angularity effect in an intentional learning condition. This result seems to support the assumption that heuristics do not play a role if people can acquire distance knowledge intentionally (Montello, 1997). But this assumption has not yet been well documented.

While there are many studies about the differences in intentional vs. incidental learning conditions in memory research (for example: Neill, Beck, Bottalico, & Molloy, 1990), there are only a few studies in spatial cognition research (for example: Mandler, Seegmiller, & Day, 1977). So far, we only know of two studies that investigate *distance estimation* under an intentional learning condition. Cohen, Weatherford, Lomenik, and Koeller (1979) showed that children in different age groups could more accurately estimate distance when they learned a route by active exploration under an intentional learning condition. Children who learned the route more passively, and did not know beforehand that they had to estimate distances, showed a greater degree of inaccuracy. Jansen-Osmann (2001) showed that features along a route increase distance estimation of the whole route, but only under an incidental learning condition. When the route was learned intentionally, features were not used as a heuristic, and even more so, in this case, distance estimation was quite accurate in relation to physical distances.

Due to the few studies, the dissociation between an intentional and an incidental learning condition seems to be difficult because it is not well known which information has already been coded automatically in an incidental learning condition. Mandler and his colleagues (1977) showed that a normal incidental condition is not truly incidental, because participants often deliberately use locations to help organize objects for recall in spatial location tasks. Therefore, the reason why heuristics are used in incidental but not in intentional learning conditions is not yet clear. Because of this difficulty we would like to focus on an intentional learning condition for distance knowledge. In the latter, participants could really concentrate their attention on the exploration and estimation process, which should not lead to any distance illusions. Until now there have been no studies that investigate the route-angularity effect under an intentional learning condition. The result of the first experiment suggests that there is no route-angularity effect during an easy task, although participants did know beforehand that they had to estimate distances. But to account for the importance of the degree of memory load, the exploration or the estimation process could be biased, even in an intentional learning condition. This might be the case if participants have to do another task during the exploration of each route or have to explore too many similar routes that interfere and cannot be remembered very accurately. To investigate this, we complicated the learning condition in such a way that participants had to learn more than three, namely, five similar routes. For that, task difficulty was operationalized through number and the similarity of the routes to be learned. We assume that participants have to use heuristics under an intentional learning condition when memory is loaded too heavily.

Experiment 2

Hypothesis

The route-angularity effect occurs under a difficult intentional learning condition.

Method

Participants

Thirty-two adults volunteered for Experiment 2—16 men and 16 women (mean age: 29.1 years). Participants were psychology students on a practical course at the Heinrich-Heine-University, Düsseldorf, where the experiment took place.

Materials

The materials were similar to those described in Experiment 1, but instead of using three routes, five routes were constructed: A short (40 units) and a long (80 units) route with two turns, a short (40 units) and a long (80 units) route with seven turns, and another straight route (C; 20 units), which was half as long as the two short paths. To distinguish between the five routes the floors were colored differently. The short route with two turns (Route A) was yellow, the long route with two turns (Route D) was green, the short route with seven turns (Route B) was red, the long route with seven turns (Route E) was blue, and the straight Route C was white. The order and direction of turns in the short routes (Routes A and B) were identical to Experiment 1 (see Fig. 2). Figure 3 shows the long routes of Experiment 2.

In the following test phase, participants received four protocol sheets, each containing a horizontal line. On this line, Route C was marked with starting point X and end point Y, whereby the length was about one third of the total length of the line. On every protocol sheet the route to be estimated was indicated. Having completed this task, the drawing task began. Participants received another A4 sheet of paper, which was segmented into four parts; each part was checkered in units (0.5 cm) and headed with the name of the route, which had to be drawn.

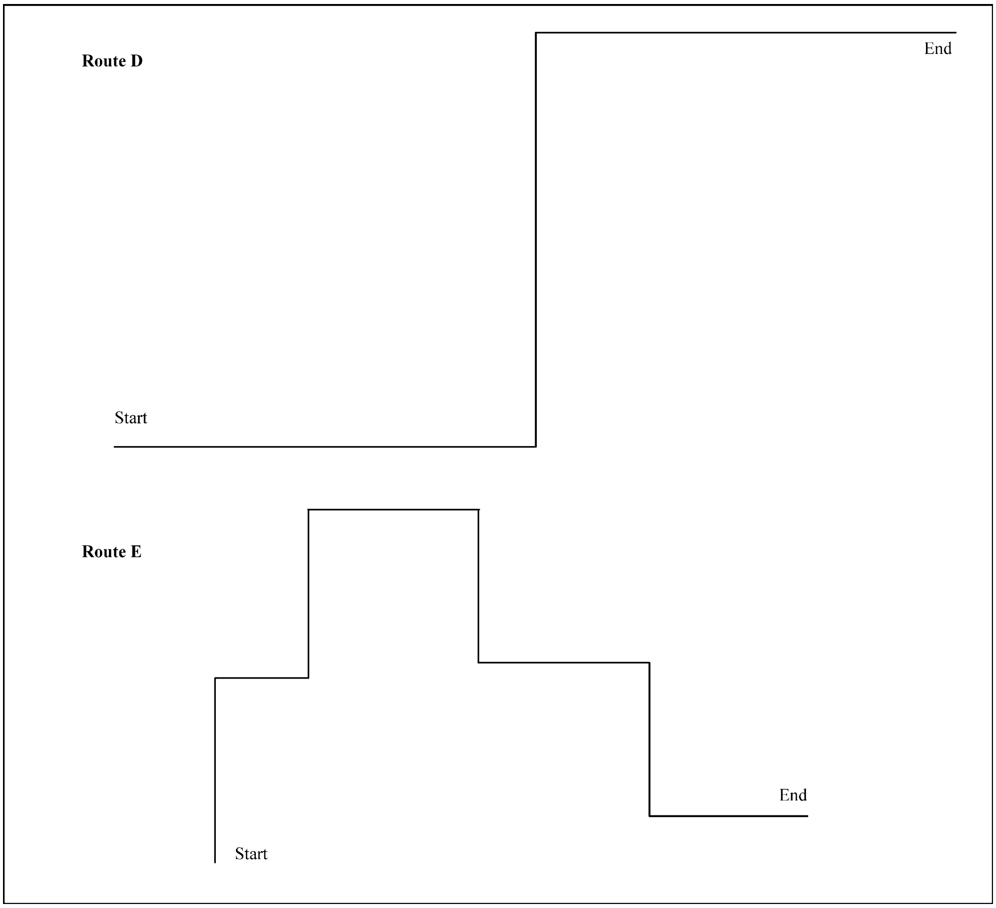

Fig. 3 Overview of the two long routes of Experiment 2

Procedure

Participants were tested individually in a single session, which lasted approximately 25 min. First of all, participants had to become familiarized with the use of a joystick—or if they were already used to it—with the special joystick's rotation and translation settings. When the navigation procedure could easily be managed, the experiment started. The participants were instructed to explore the five routes. The exploration of the four routes with turns was followed by the exploration of the route without turns. To control velocity, it was requested that the participants push the joystick as far as possible, which resulted in an appropriate moving speed. Furthermore, participants were not allowed to turn backwards or stop. Every route had to be explored twice consecutively. The time needed to explore the routes was registered. In advance, participants were informed that they had to estimate the distances of the routes at the end of the experiment. The order of exploration of the first four routes was balanced. After exploring the fifth route distance estimation was tested by ratio-estimation (see Experiment 1). Afterwards, participants had to draw every single route on one of the four parts of the protocol sheet. The marked and drawn lengths were measured in millimeters.

Experimental design

There were two experimental factors: KIND OF ROUTE (Route A with two turns; Route B with seven turns) and LENGTH OF ROUTE (short route—40 units, long route—80 units). Both factors were manipulated within participants.

There were four dependent variables:

1. Estimate of the route length via ratio- estimation (measured in millimeters)
2. Length of the drawn routes (measured in millimeters)
3. Number of turns in the drawing
4. Time needed to explore the routes

Results

Distance estimation (ratio-estimation technique)

Figure 4 (left side) shows the mean values and standard errors of the route lengths estimated via ratio-estimation. There was a significant influence of the factor "KIND OF ROUTE," $F(1,31) = 9.4, p < .005$. Routes with two turns ($\bar{x} = 123.85$ mm, $s_{\bar{x}} = 6.89$) were estimated to be shorter than routes with seven turns ($\bar{x} = 140.13$ mm, $s_{\bar{x}} = 7.4$). Furthermore, there was a significant influence of the factor "LENGTH OF ROUTE," $F(1,31) = 22.2, p < .001$. The longer routes ($\bar{x} = 146.49$ mm, $s_{\bar{x}} = 7.82$) were estimated to be longer than shorter ones ($\bar{x} = 117.52$ mm, $s_{\bar{x}} = 6.77$). There was no significant interaction between these two factors, $F(1,31) = 3.1$, n.s.

Distance estimation (drawing technique)

Figure 4 (right side) shows the mean values and standard errors of the *drawn* route lengths. Routes with two turns ($\bar{x} = 78.93$ mm, $s_{\bar{x}} = 4.44$) were drawn shorter than routes with seven turns ($\bar{x} = 92.28$ mm, $s_{\bar{x}} = 4.72$); the difference was significant, $F(1,31) = 7.27$, $p < .05$. Furthermore, shorter routes ($\bar{x} = 78.72$ mm, $s_{\bar{x}} = 4.36$) were drawn shorter than longer routes ($\bar{x} = 92.5$ mm, $s_{\bar{x}} = 4.49$); $F(1,31) = 10.26$, $p < .01$. There was no significant interaction between these two factors, $F(1,31) = 0.1$, n.s.

Drawing of the routes

There was a significant influence of KIND OF ROUTE, $F(1,31) = 50.21$, $p < .001$. The routes containing two turns were drawn with a mean of 2.92 turns ($s_{\bar{x}} = 0.29$), the routes with seven turns with a mean of 5.36 turns ($s_{\bar{x}} = 0.35$).

Exploration time

The time needed to explore the shorter and longer routes differed significantly, $F(1,31) = 1143.71, p < .001$. Less time was needed to explore the shorter routes ($\bar{x} = 44.48$ s, $s_{\bar{x}} = 1.46$) than for the longer ones ($\bar{x} = 83.27$ s, $s_{\bar{x}} = 1.12$). There was no difference concerning the exploration time for the routes with two and seven turns. Therefore, objective exploration time can be ruled out as an explaining factor for the difference in

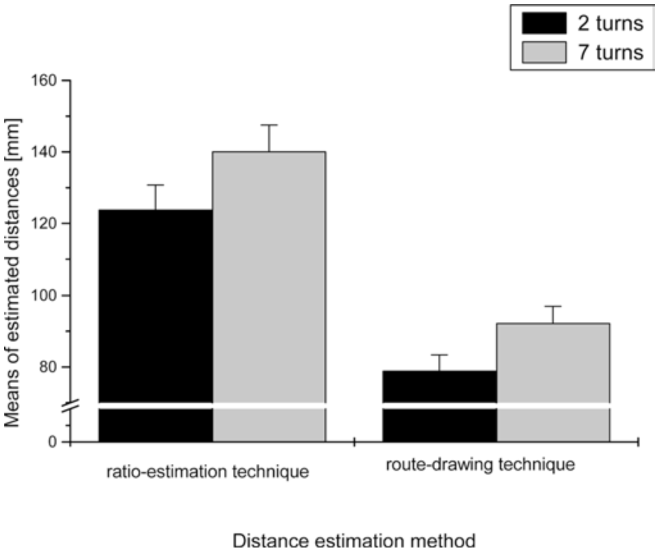

Fig. 4 Means and standard errors of estimated route lengths (ratio-estimation technique and route-drawing technique) of Experiment 2

results between routes with seven vs. routes with two turns.

Discussion

Experiment 2 demonstrated a route-angularity effect under an intentional learning condition. This result does not depend on the objective exploration time, which did not differ for the different kinds of routes (two vs. seven turns). Furthermore, the result was stable across two different distance estimation methods, ratio-estimation and route-drawing. The difference from Experiment 1 was that the intentional learning condition was more difficult because participants in Experiment 2 had to learn more paths, five in all, before the distances had to be estimated. The results show that even if participants knew that they had to estimate distances the route-angularity effect occurred. This is in contrast to the studies mentioned above (Cohen et al., 1979; Jansen-Osmann, 2001; Montello, 1997) and might be due to task difficulty during the estimation process. Participants could not remember scanned exploration time or counted regular patterns—like the number of bricks in the wall, which was hardly possible in this kind of controlled environment anyway. This is an important result because it refutes the assumption that heuristics do play an important role under an intentional learning condition.

General discussion

The route-angularity effect describes the distortion of distance in the way that a route with more turns appears to be longer than a route of the same length with fewer turns. The fundamental finding of the present experiments was that the route-angularity effect is found when people have a high memory load, in terms of having to keep track of distances among multiple paths at the same time. Even under an intentional learning condition, this kind of distance illusion appears when the learning of one route interferes with the other.

None of the explanations by Sadalla and Magel (1980), the storage-, the scaling, or the effort hypotheses, could explain the importance of memory load. So the question is, what is the mechanism by which a high memory load leads to the route-angularity effect? From a memory- based approach, we can assume that task difficulty prevents the distance from becoming encoded and stored deeply (compare “levels of processing”, Craik & Lockhardt, 1972) or retrieved correctly. Eysenck (1979) found that memory traces that are distinctive are more readily retrieved than those resembling other memory traces. This was the case in the learning of the four similar routes in Experiment 2 and leads us to the “context effect” phenomenon. The literature offers a wide range of evidence that certain features can establish contexts that influence distance estimations in specific ways. For example, Holyoak and Mah (1982) showed that reference points can distort subjective distances. Their account of this effect, the implicit scaling model, has been extended to also account for the effects of reference points on the retrievability of other spatial features (contextual scaling model; McNamara & Diwadkar, 1997).

In addition, we can integrate the results into a more general theory of cognitive psychology. The more uncertainty people have, given the input from a sensory system, the less they will rely on sensory information and the more likely they will rely on heuristics. Turn counting is one heuristic, as well as that for remembering unreliable sensory cues or the subjective time, the time people think they have needed for exploration (Montello, 1995, 1997). Radvansky, Carlson-Radvansky, and Irwin (1995) have already investigated the role of uncertainty in estimating pictorial distances from memory. They found that distance estimations were more accurate when participants’ confidence was high. Deviations in estimation are a result of an inability to accurately retrieve all the information needed to make the estimation rather than for compression in memory. The authors discussed their argument in the context of the category adjustment model by Huttenlocher, Hedges, and Duncan (1991) and argued that systematic errors are due to a two-fold process: A fine-grained memory process of the physical property that stores an unbiased record of the external property, and a categorization process that divides the stimuli along several dimensions. When uncertain about a particular stimulus value, because of an impaired fine-grained memory (or in our case the perceived objective route length), participants use the categorization process to assist this estimation; they report a value that is closer to the prototypical category. This categorization serves as a heuristic to solve the distance estimation task. The use of heuristics has already been investigated in detail in general research on judgment (Kahneman, Slovic, & Tversky, 1982). In this context the numerosity hypotheses, which was explored by Pelham, Sumarta, and Myaskovsky (1994) does play an important role. This heuristic describes a tendency to over-infer quantity. Pelham et al. (1994) showed that people do indeed seem to succumb to a bias when the task is difficult. Their participants were asked to estimate the area of a circle when it was complete or when it was cut into slices. Estimates were higher for the pieces, and even more if these pieces were arranged in a straight line. Furthermore, the response time was higher for the estimation of many small elements than for fewer large ones, but only for a difficult condition, when participants had to solve a second task simultaneously. Manktelow (1999, p. 182) assumes:”...difficult problems make it hard for us to use our higher-order processes, and we fall back on a crude numerosity = quantity heuristic, along with chickens and rats.”

In summary, we can assume that heuristics are always used when working memory capacity is overloaded.

For this reason it seems quite reasonable to investigate the encoding, storage, and retrieval of distances in an environmental space while completing a second task, and how it has already been done for studies on path integration (May & Klatzky, 2000). Further experiments on high-memory load could be easily carried out in virtual environments, which are increasingly appreciated in spatial cognition research. These environments were chosen because they offer the possibility of running strictly controlled experiments in a nearby, realistic setting. Some of the main advantages of virtual environments are that they allow for the creation of environments of different complexity, on-line measurement during navigation, the control of the amount of exposure to the environment and the type of landmarks, including their position (Péruch, Belingrad, & Thinus-Blanc 2000). The appropriateness of virtual environments as a tool to investigate spatial cognition has already been evaluated by studies in which results obtained in physical spaces were replicated in a virtual environment. For example, Ruddle, Payne, and Jones (1997) were able to replicate the results of direction and distance knowledge obtained in real-world settings (Thorndyke & Hayes-Roth, 1982) in a virtual environment. Virtual environments allow participants to acquire distance knowledge (Jansen-Osmann & Berendt, 2002; Willemsen & Gooch, 2002), knowledge about directions (Albert, Rensink, & Beusmanns, 1999), and route and survey knowledge (Gillner & Mallot, 1998; Jansen-Osmann, 2002). However, next to the positive aspects there seem to be some potential drawbacks, especially when using desktop virtual reality systems that do not involve proprioceptive sensory information (Witmer, Bailey, Knerr, & Parsons, 1996). This assumption is discussed in the literature. Waller, Knapp, and Hunt (2001) showed that there was no difference between learning the spatial representation of mazes in wire-frame virtual conditions and in real-world conditions. Furthermore, Westerman, Cribbin, and Wilson (2001) showed that the efficiency of navigation was poorer in an immersive virtual situation than in a desktop virtual situation. There are some concerns regarding distance estimation. Witmer and Sadowski (1998) showed relative underestimation of distances in virtual environments compared with real environments. But Witmer and Kline (1998) showed that traversing this distance in a larger virtual environment improves the ability to estimate that distance. Jansen-Osmann and Berendt (2002) showed that results obtained in a real-environment concerning the influence on turns of distance estimation by Sadalla and Magel (1980) could be replicated in a virtual environment. Since the advantages can't be ignored, therefore, it seems quite legitimate to use virtual environments in distance cognition research.

To conclude, we have shown that the results of the two experiments provide evidence that the route-angularity effect is a memory-based effect that depends on how memory is loaded. Further memory-based research has to be conducted using virtual environments as an appropriate experimental environment.

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