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The Metrics of Spatial Distance Traversed During Mental Imagery

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The authors conducted 2 experiments to study the metrics of spatial distance in a mental imagery task. In both experiments, participants first memorized the layout of a building containing 10 rooms with 24 objects. Participants then received mental imagery instructions and imagined how they walked through the building from one room to another. The authors manipulated Euclidean distance involved in these imaginary motions: Spatial distance measured in centimeters on the layout was either short or long. Independently, they varied categorical distance: The motions led through one room or two rooms. The time needed to imagine motions and response times to test probes indicated that both Euclidean distance and categorical distance affected mental imagery. The authors discuss the new finding of categorical distance effects in mental imagery and relate the results to earlier failures to find Euclidean distance effects in formally equivalent studies of narrative comprehension.

In humans' everyday life, the space surrounding us possesses Euclidean metrics. For instance, objects located 10 m away from us are twice as distant as objects located 5 m away, and a distance of 100 m remains unchanged, no matter whether it is divided into 2 units of 50 m or 100 units of 1 m. This does not imply, however, that our mental representations of space follow the same rules, particularly the rule that these representations preserve the Euclidean metrics of spatial distance. One task that has been claimed to involve the use of Euclidean distance information is mental imagery. Mental imagery is a cognitive process that makes the figural aspects of previously seen objects, or scenes when these are no longer accessible to perception, temporarily available to the mind (e.g., Denis, 1991; Kosslyn, 1994; Paivio, 1991; Richardson, 1999). Imagery reinstates quasi-pictorial internal experiences that reconstruct the figural appearance of objects (including their color, shape, internal structure, etc.).

One of the very special properties of mental imagery is that it conveys information on the spatial structure of configurations in an analog fashion. For instance, when reconstructing the appearance of a multipart object or configuration, imagery is assumed not only to preserve gross topological relationships among these parts but to preserve the metric information on the distances separating parts of the configuration. This assumption has received the strongest empirical support from studies on mental scanning (for a review, see Denis & Kosslyn, 1999). The mental scanning paradigm consists of asking people who have learned a visual configuration to reconstruct its visual appearance and mentally scan across their image of that configuration. Measures of scanning times between landmarks have repeatedly been shown to correlate with the actual distances in the original configuration, a finding interpreted as showing that Euclidean distances are effectively represented in mental images, provided that sufficient time of exposure to the original input has been managed (e.g., Kosslyn, Ball, & Reiser, 1978; Pinker, Choate, & Finke, 1984). To summarize, the correlation between scanning times and distances is taken to indicate that during mental imagery, information on Euclidean distance is preserved accurately, and that the structure of images reflects the structure of previously perceived objects in an analog fashion.

A relevant extension of this type of research pertains to the possibility for language to elicit the construction of mental images. Distinct from the photographic images resulting from previous processing of visual inputs, novel images can be created, for instance, from texts describing spatial configurations. When people create images of a never-seen object and perform mental scanning across the newly constructed configuration, the persistence of the mental scanning effect suggests that mental images derived from language also include information on distances and that this information is available to inspection in ways similar to those for images derived from visual experience (cf. Denis & Cocude, 1992, 1997; Denis & Zimmer, 1992). Euclidean distances are thus thought to be represented in text- or language-based mental images, just as they are represented in images that recreate previous visual experiences.

There are two problems associated with this widely held assumption, however. First, the mental scanning task employed so far is prone to the problem of *demand effects* (see Pylyshyn, 1981; Richman, Mitchell, & Reznick, 1979): Participants may deliberately produce longer reaction times when asked to scan across larger distances. Although good evidence is available indicating

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that mental scanning is not completely reducible to such demand effects (see Denis & Kosslyn, 1999; Pinker et al., 1984), we need converging evidence for the effects of Euclidean distance on mental imagery from tasks that are less prone to explanations by demand effects. Second, up to now mental imagery research has ignored the fact that there are different metrics of *spatial distance*, and that there is at least one other type of spatial distance involved in mental scanning besides Euclidean distance: *categorical distance*. Categorical distance refers to the number of units that are traversed during mental scanning, for instance, landmarks on an island map, rooms in a building, or counties in a state. Thus, categorical distance is restricted to measurements on an ordinal scale level. *Euclidean distance*, in contrast, is more fine-grained: It is measured on an absolute scale level, allowing for relative comparisons. The neglect of categorical distance in mental imagery research is regrettable. Sometimes, categorical distance is confounded with Euclidean distance (cf. Lea, 1975). Thus, it is impossible to determine whether both variables affect scanning times, whether they interact, and whether Euclidean distance has an effect over and above categorical distance. Indeed, there is reason to doubt the latter assumption, with negative evidence coming from text comprehension research. For instance, Rinck, Hähnel, Bower, and Glowalla (1997) found that effects of spatial distance represented in situation models of short narratives were categorical only, with no evidence for effects of Euclidean distance.

It is fortunate that previous research on spatial distance effects in narrative comprehension not only raises doubts regarding spatial distance effects in mental imagery but also provides means to solve both the demand-characteristics problem and the metrics problem. In short, one may avoid alternative explanations referring to demand characteristics by using measures that are less prone to demand effects, and one may solve the metrics problem by varying levels of categorical distance and levels of Euclidean distance independently of each other. Although in a formal hierarchy of geometries, Euclidean metrics and categorical metrics are not independent of each other (cf. Klein, 1968), their mental representations may be independent, and they may be varied independently of each other. To this end, we adopted an experimental procedure developed by Morrow and his colleagues (e.g., Morrow, Greenspan, & Bower, 1987).

In the two experiments reported in this article, participants first memorized the layout of a building with a number of rooms and objects located in it, as in previous studies of narrative comprehension. Unlike in these studies, however, participants then read a series of mental imagery instructions rather than statements describing the motions of a fictitious protagonist. The instructions contained *critical motion instructions* asking the participants to imagine how they moved from one room (the *source room*) through a number of unmentioned *path rooms* into another room (the *location room*); for example, *You walk from Hall 6 into Hall 8* (see the Appendix and Figure 1). The experimental manipulations pertained to the path rooms: We varied Euclidean distance by making the path involved in the motion instructions either short or long (measured in centimeters on the layout), and we varied categorical distance by dividing the path into two rooms or leaving it undivided. The accessibility of objects memorized earlier was probed by object test probes that followed the motion instructions: At several unpredictable points in each narrative, the imagery task was interrupted by test probes consisting of pairs of previously learned object names. For each test probe, the participants had to decide as quickly as possible whether the two objects were located in the same room or in different rooms.

If Euclidean distance is indeed affecting mental imagery, the accessibility of objects referred to—and therefore, the test-probe response times—should be affected by the length of the path: Objects close to the currently imagined location of the participant should yield faster responses than do more distant objects. If, on

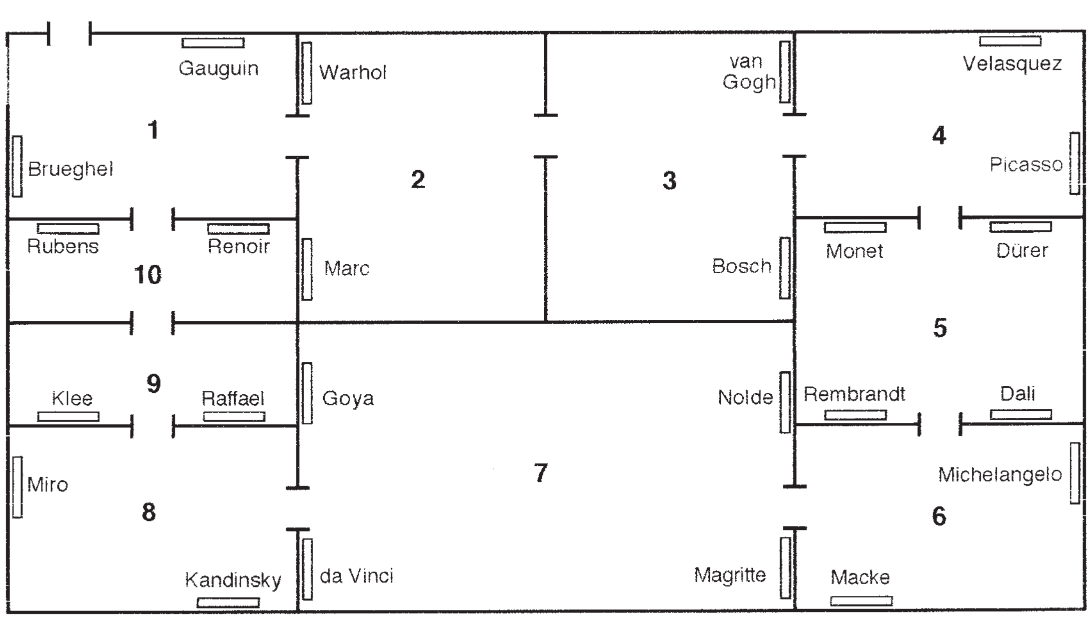

Figure 1. Sample building layout in horizontal orientation memorized by participants.

the other hand, categorical distance has an effect, the number of path rooms should affect response times. A similar line of reasoning applies to motion instructions: Imagining the complete path should take longer the longer the path is and the more rooms are traversed. The dependency of response times on mental spatial distance has been called the spatial distance effect, and the critical question is whether in the case of mental imagery, spatial distance should be thought of as Euclidean distance, categorical distance, or both. The use of test probes in addition to imaginary motion instructions is particularly helpful, because the probe task should be less prone to demand characteristics than mental scanning or other tasks employed in mental imagery research (see Pylyshyn, 1981). Instead of asking participants to produce response times depending directly on traversed distance, we asked them to respond as quickly as possible in each case, no matter what type of probe or amount of distance from the focus of attention was involved.

Experiment 1

We designed Experiment 1 to assess the role of Euclidean distance and categorical distance in mental imagery. In general, Experiment 1 was similar to the Experiment 3 of Rinck, Williams, Bower, and Becker (1996). In the first part, participants studied the layout of a fictitious building, and in the second part, they received mental imagery instructions to imagine their own actions in that building. The structure of the building was varied exactly as it was in the experiments by Rinck et al. (1997), creating short versus long paths leading through a single path room or through two path rooms.

Method

Participants. Twenty-eight Dresden University of Technology, Dresden, Germany, students participated in this experiment, compensated by course credit or a small monetary payment that was equivalent to $5. We excluded the data for an additional participant from all analyses because the participant failed to learn the building layout within the given time limit.

Layout learning. In the first part of the experiment, participants learned the layout of a fictitious art museum. The building consisted of 10 halls, each of which contained either 2 or 4 paintings, for a total of 24 paintings. Each painting belonged to a different famous artist, and the paintings were denoted by the artists' names (e.g., Goya, da Vinci, Nolde, and Magritte; see Figures 1 and 2). The artists' names were distributed randomly across the building in order to avoid preexperimental associations between paintings located in the same hall. Structurally, the building was an exact copy of the research center employed in the Rinck et al. (1997) experiments: It contained the same number of critical objects (here paintings) in the same locations of the same building layout. The doors were also identical: One door led to the outside (from Hall 1), and the other doors connected the halls in a way that allowed only for clockwise or counterclockwise motions from one hall to another (see Figures 1 and 2).

Participants studied the layout for 1 min and then turned it over and were given a blank diagram containing only the walls and doors of the building. They were asked to recall by writing all the hall numbers and artists' names they could remember on their correct locations on the layout. They compared their work with the original layout and noted errors. Participants proceeded through such self-paced study–test cycles until they could perfectly reproduce all halls and paintings in their correct locations. Afterward, they answered eight questions about locations of halls and paintings in the building. Participants required approximately 30 min to learn the layout and answer the questions perfectly.

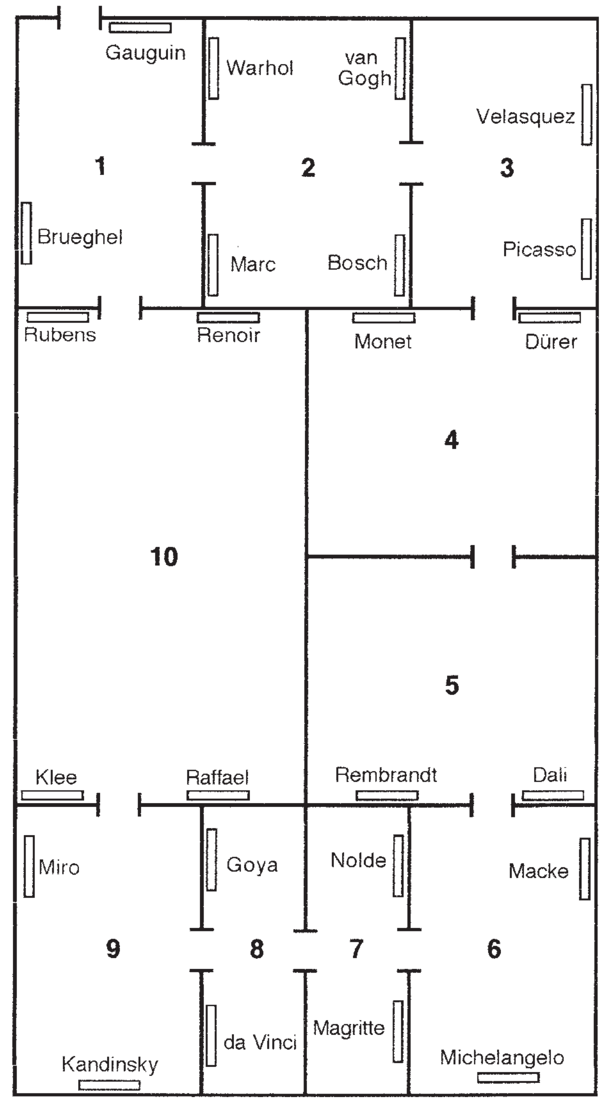

Figure 2. Sample building layout in vertical orientation memorized by participants.

Figure 1 displays one of the four layouts used in Experiment 1. All layouts were approximately 12 × 24 cm in size and showed the museum with 24 objects located in 10 rooms (not necessarily the same 10 rooms for all participants). In the mental imagery task, the 4 corner rooms always served as source rooms and location rooms for critical imaginary motions, namely, the rooms denoted Halls 1, 4, 6, and 8 in Figure 1 (e.g., *You walk from Hall 4 into Hall 6*). These rooms were identical for all participants. The remaining rooms always served as path rooms for the critical motions, namely, the rooms denoted Halls 2, 3, 5, 7, 9, and 10 in Figure 1. The appearance of the paths was systematically varied: Each of them could be either short or long. Independently, a path could lead through a single path room or through 2 rooms. For participants who studied the layout shown in Figure 1, Hall 5 and Hall 7 were depicted as single rooms; Hall 5 was short, and Hall 7 was long. For the same participants, the corresponding paths on the other side of the building led through 2 rooms, namely a short path through Halls 9 and 10 and a long path through Halls 2 and 3 (see Figure

1). In each diagram, two motion paths were over a short Euclidean distance, and two were over a long distance. Moreover, two paths led through a single path room, and two led through 2 rooms. Full combination of both variables yielded the possible four combinations of Euclidean distance and categorical distance: one-room short path, two-room short path, one-room long path, and two-room long path. Participants were not informed about these systematic variations.

To counterbalance the materials and the experimental conditions, four different layouts were used. Each path was depicted equally often as one-room short, two-room short, one-room long, and two-room long. We varied path length by drawing the layout either wider than it was high (a 1:2 ratio, see Figure 1) or higher than it was wide (a 2:1 ratio, see Figure 2). We varied the number of path rooms by including a separating wall along the path or by leaving it out. For instance, the path between the hall in the lower left-hand corner and the hall in the lower right-hand corner of the building could involve a single room (Hall 7 in Figure 1), or the path could be divided into 2 rooms (Hall 7 and Hall 8 in Figure 2). Note that the paths, when divided into 2 rooms, were still of the same length as the undivided paths. For each participant, only two of the four paths were divided; therefore, each layout contained 10 rooms. Each room contained two objects, except for those in undivided paths, which contained four objects each (see Figure 1). These counterbalancing procedures yielded four different layouts, and participants were randomly assigned to learn one of the layouts. This rather elaborate procedure was undertaken to reduce error variance: During the subsequent imagery task, identical verbal materials could be used for motion instructions and test probes in different experimental conditions, because the experimental differences had been created during the preceding learning of the layouts.

Mental imagery task. In the second part of the experiment, participants received mental imagery instructions, which were presented one instruction at a time on the screen of an Apple Macintosh computer, controlled by RSVP software (Williams & Tarr, n.d.). The participants were asked to imagine themselves performing actions that had taken place in the previously learned environment. Presentation of the instructions was self-paced: Participants pressed the space bar of the computer keyboard to advance from one instruction to the next. They were asked not to advance to the next instruction before they had created a complete mental image of the contents of the current instruction. They were also told to close their eyes if they felt this would facilitate the creation of mental images. A translated excerpt of the experimental instructions used in Experiment 1 is given in the Appendix.

Each participant received a total of 206 instructions, which contained actions such as looking at paintings, sitting down and getting up, or moving from one point to another. Of these motion instructions, 32 were critical. They described a complete motion event in which the participant walked from a source room (located in one of the building's corners) through unmentioned path rooms into a location room (located in another corner). For instance, one motion instruction read *You walk from Hall 6 into Hall 8* (see the Appendix and Figure 1). After the participant imagined this motion, the location room was his or her current mental location. Each critical motion instruction was followed by an experimental object-pair test probe. These test probes consisted of two previously learned painting names presented in the center of the screen instead of the next motion instruction. Whenever one of these test probes appeared, participants had to decide whether the two paintings were located in the same room or in different rooms. For all of the 32 experimental test probes, the correct answer was yes, and the two paintings were either located in the part of the path room(s) close to the current mental location of the participant or in the far part of the path room(s). For the example stated above, in which Hall 8 of Figure 1 is the current location, Goya and da Vinci were in the close part, whereas Magritte and Nolde were in the far part (see the Appendix and Figure 1).

For each participant, half of the critical motion instructions described clockwise movements through the building, and the other half described counterclockwise movements. Each pair of paintings served equally often as a close-part test probe and as a far-part test probe. In addition to these critical test probes, another 36 test probes were presented at unpredictable positions. These dummy probes served to break the regular pattern of positive probes following the motion instructions: The majority of them (24) required a "no" response, and 12 of them involved the pronoun *you* together with the name of a painting (e.g., *You–Miro*). In case of these participant probes, the participants' task was to indicate whether they were currently located mentally in the same room as the denoted painting. These probes forced participants to integrate the mental imagery instructions with their previously acquired knowledge of the spatial layout (see Wilson, Rinck, McNamara, Bower, & Morrow, 1993). Participants were instructed to work carefully but at their natural speed. Reading times of mental imagery instructions as well as correctness and latencies of test-probe responses were recorded by the computer. Participants took about 30 min to complete this part of the experiment, after which they were paid and debriefed.

Design. For motion instructions, full combination of the factors path length (short vs. long) and number of path rooms (one vs. two) yielded a 2×2 design. Both factors were varied within subjects. For object-pair test probes, location of the objects (close vs. far part of the path) was an additional within-subjects factor. Following a suggestion by Pollatsek and Well (1995), we included the counterbalancing factor of layout type as a four-level between-subjects factor in the analyses. The dependent variables of interest were reading times of critical motion instructions and response times to critical test probes. For motion instruction reading times, the critical question was whether they would vary with Euclidean distance and categorical distance between the source room and the location room. Similarly, for test-probe response times, we sought to determine whether the difference between close and far objects depended on Euclidean distance and categorical distance between them.

Results and Discussion

Motion instruction reading times and path-room object probe response times were analyzed after data trimming to exclude outlier times from the data: For each separate dependent variable and each experimental condition, we excluded data differing from the mean by more than 2 standard deviations from the analyses. We subjected the remaining data to analyses of variance (ANOVAs) followed by planned contrasts using two-tailed t tests. All effect sizes reported below are f values according to Cohen (1988). We treated the data of Experiment 2 in the same way.

Motion instructions. The mean motion instruction reading times observed in Experiment 1 are shown in the upper part of Table 1. The ANOVA of these reading times revealed that both Euclidean distance and categorical distance affected reading times of imagined motions. Participants took longer to imagine the motions when the path was long rather than short, $F(1, 27) = 4.38$, $p < .05$; $f = .11$, and when the path consisted of two rooms rather than one, $F(1, 27) = 5.47$, $p < .05$; $f = .12$. Path length and number of path rooms did not interact significantly, $F(1, 27) < 1$.

Path-room object probes. The mean response times for path-room object probes are shown in the upper part of Table 2. The ANOVAs of these response times revealed a clear effect of spatial distance: Participants responded more quickly when the two objects contained in the test probe were located in the close part of the path rather than the far part, $F(1, 27) = 6.13$, $p < .05$; $f = .13$. The only exception to this rule occurred when the objects were located in a single short room. In this case, there was no difference between response times to close objects and response times to far objects, $t(27) < 1$. Thus, if neither Euclidean distance nor cate-

Table 1
Mean Reading Times of Critical Motion Instructions in ms in Experiments 1 and 2

	Path length			
	Short		Long	
No. of path rooms	*M*	*SE*	*M*	*SE*
Experiment 1 ($N = 28$)				
1	2,196	97	2,276	125
2	2,432	115	2,651	131
Experiment 2, room-to-room ($N = 40$)				
1	2,418	136	2,581	159
2	2,729	154	2,908	144
Experiment 2, object-to-object ($N = 40$)				
1	2,405	123	2,667	141
2	2,786	155	2,990	149

gorical distance provided a clear distinction between the close part of the path and the far part, no spatial distance effect occurred. If the short path was divided into two rooms, however, objects in the far part were less accessible than those in the close part, $t(27) = 2.48$, $p < .05$; $f = .10$, confirming the representation of categorical distance. The same was true when the single room was long, $t(27) = 2.18$, $p < .05$; $f = .09$, confirming the representation of Euclidean distance. Finally, if the path was both long and divided, the difference between close objects and far objects was also significant, $t(27) = 2.91$, $p < .05$; $f = .15$. Additional analyses revealed that the zero difference observed for single short rooms differed significantly from the close–far differences observed for the other three combinations of path length and path room number, all $Fs(1, 27) > 4.69$, $p < .05$; $f > .11$.

Taken together, the results of Experiment 1 suggest that both Euclidean distance and categorical distance were represented during the mental imagery task. The length of the path as well as the number of path rooms affected reading times of imagined motions and response times to object probes.

Experiment 2

We designed Experiment 2 to replicate and extend the results of Experiment 1 by introducing two methodological improvements. Although the effects of Euclidean distance and categorical distance observed in Experiment 1 were significant, they were rather weak. A simple reason for this may have been insufficient statistical power due to the limited sample size of Experiment 1 (28 participants). Therefore, we studied a larger sample of 40 participants in Experiment 2. Another reason may lie in the motion instructions of the type *You walk from the source room into the location room*. These instructions are somewhat vague because they specify neither the start nor the end of the motion exactly. Consequently, mental images created in response to these instructions may vary considerably, introducing an undesirable amount of error variance. Therefore, two different types of motion instructions were used in Experiment 2: In addition to the *room-to-room* instructions used before, more precise *object-to-object* instructions were presented to the participants, as in *You walk from the Picasso to the Michelangelo*. If mental images created by the participants are precise enough to represent Euclidean distances at a fine-grained level, these object-to-object instructions should reduce variance in the imagined motions, thereby improving statistical power.

Method

This experiment was very similar to Experiment 1. Therefore, we describe only the differences.

Participants. Forty Dresden University of Technology students participated in this experiment, compensated by course credit or a small monetary payment that was equivalent to \$5. We excluded the data for 2

Table 2
Mean Path Room Object Probe Response Times in ms in Experiments 1 and 2

	Path length and object location							
	Short				Long			
	Close		Far		Close		Far	
No. of path rooms	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Experiment 1 ($N = 28$)								
1	3,485	141	3,456	135	3,168	165	3,543	158
2	3,167	139	3,439	166	3,260	140	3,491	136
Experiment 2, room-to-room ($N = 40$)								
1	2,881	202	3,179	187	2,963	147	3,183	170
2	2,868	199	3,159	201	2,981	192	3,277	175
Experiment 2, object-to-object ($N = 40$)								
1	2,553	142	2,989	177	2,410	121	3,038	186
2	2,531	155	2,877	160	2,537	155	2,937	172

additional participants from all analyses because they failed to learn the building layout within the given time limit.

Layout and mental imagery instructions. We adopted the layouts of Experiment 1 without any changes. The mental imagery instructions were also very similar; they differed from those of Experiment 1 only because the new object-to-object motion instructions were introduced. For each participant, half of the 32 motion instructions were changed to object-to-object instructions, whereas the other half remained room-to-room instructions. For instance, the instruction *You walk from Hall 4 into Hall 6* was changed to *You walk from the Picasso to the Michelangelo* (see Figure 1). We created two sets of materials to ensure that across participants, each motion was described equally often by a room-to-room instruction and an object-to-object instruction.

Results and Discussion

Room-to-room motion instructions. The mean reading times of the room-to-room instructions observed in Experiment 2 are shown in the middle part of Table 1. The 2 × 2 ANOVA of these reading times yielded results that replicated those of Experiment 1 only partially. Participants took significantly longer to imagine the motions when the path consisted of two rooms rather than one, $F(1, 39) = 6.63$, $p < .05$; $f = .13$, demonstrating the effect of categorical distance on mental imagery. The effect of Euclidean distance was not significant, $F(1, 39) = 1.65$, *ns*; $f = .05$, although reading times were longer for long paths than they were for short ones. As before, Euclidean distance and categorical distance did not interact significantly, $F(1, 39) < 1$.

Object-to-object motion instructions. The mean reading times of these instructions are given in the lower part of Table 1. The analyses of these reading times indicated similar but stronger effects of Euclidean distance and categorical distance than those observed for room-to-room instructions. Participants took longer to imagine the motions when the path was long rather than short, $F(1, 39) = 4.48$, $p < .05$; $f = .10$, and when the path consisted of two rooms rather than one, $F(1, 39) = 14.41$, $p < .01$; $f = .20$. Again, path length and number of path rooms did not interact significantly, $F(1, 39) < 1$.

Room-to-room test probes. The mean response times for test probes after room-to-room motion instructions are shown in the middle part of Table 2. The 2 × 2 × 2 ANOVA of these probe response times revealed a significant effect of spatial distance: Participants responded more quickly when the two objects contained in the test probe were located in the close part of the path rather than the far part, $F(1, 39) = 12.31$, $p < .01$; $f = .18$. Neither path room number nor path length interacted with object location, both $Fs(1, 39) < 1$. The spatial distance effect was observed for each of the four possible combinations of path length and number of path rooms, all $ts(39) > 5.96$, $p < .05$; $f > .14$; see Table 2. Because of increased statistical power, the spatial distance effect was significant even with short, single-room paths. Thus, neither path length nor number of path rooms interacted significantly with the spatial distance effect, both $Fs(1, 39) < 1$. As before, we found no evidence for any dominance of categorical distance over Euclidean distance in probe response times. Instead, both types of spatial distance yielded very similar effects.

Object-to-object test probes. The mean response times for test probes following object-to-object motion instructions are shown in the lower part of Table 2. The 2 × 2 × 2 ANOVA of these probe response times revealed yet another clear effect of spatial distance: Participants responded more quickly when the two objects contained in the test probe were located in the close part of the path rather than the far part, $F(1, 39) = 22.53$, $p < .01$; $f = .25$. As before, neither path length nor number of path rooms interacted significantly with this spatial distance effect, both $Fs(1, 39) < 1$: The effect was observed for each of the four possible combinations of path length and number of path rooms, all $ts(39) > 5.56$, $p < .01$; $f > .17$ (see Table 2). In sum, the results observed for these test probes are very similar to those of the room-to-room probes. Moreover, as expected, the effects were stronger for the current object-to-object probes.

Taken together, the results of Experiment 2 provide a replication and extension of Experiment 1. As before, we observed effects of Euclidean distance and categorical distance on latencies of creating mental images. The effects on room-to-room test probes were statistically more reliable than they were in Experiment 1; this is probably because of the increased sample size. As a result, even small differences in Euclidean distance sufficed to make objects located in the close part of a short, single room more accessible than objects in the far part of this room. Also as predicted, the more precise object-to-object instructions yielded clearer effects than did room-to-room instructions.

General Discussion

Our motivation in the present research was to better understand how people represent spatial distances when they imagine themselves traversing these distances. In particular, we designed the two experiments reported here to identify the metric properties of spatial distance used in mental imagery: Is mental imagery affected by both Euclidean distance and categorical distance? Compared with earlier studies of mental imagery, these experiments showed two advantages: First, both Euclidean distance and categorical distance were varied independently of each other, avoiding possible confounds. Second, the results are less prone to alternative explanations by demand characteristics because we did not rely solely on reading times of mental imagery instructions.

To achieve these goals, we had to meet two important methodological prerequisites. First, we needed to use a paradigm that would allow for the independent variation of Euclidean distance and categorical distance. We chose the map-learning-plus-narrative-reading paradigm, originally devised by Morrow, Rinck and their colleagues (Morrow et al., 1987; Rinck et al., 1997), because it fulfills this requirement, as Rinck et al. (1997) have shown. We adapted the paradigm here to the study of mental imagery by recording the duration of imaginary motions as had been done before by Rinck et al. (1996). We intended the motion instructions used here to elicit a cognitive activity that would be a variant of mental scanning (Denis & Kosslyn, 1999). Second, we needed a way to measure spatial distance effects during mental imagery other than collecting reading times of mental imagery instructions, which have been criticized for being sensitive to demand characteristics (Pylyshyn, 1981; Richman et al., 1979). Therefore, we measured response times to object test probes in addition to reading times of mental imagery instructions.

Having taken these precautions, we can summarize the results collected in Experiments 1 and 2 as follows. Participants memorized the layout of a multiroom building in which each room contained several objects and were subsequently invited to read instructions to perform imaginary walks from room to room or object to object. The walking distances were manipulated both in terms of Euclidean distance (walking along a short path vs. a long path) and categorical distance (walking through one or two rooms). The first measure of interest was the time taken to imagine motions. This time was reliably longer when participants imagined motions along longer paths and also when the paths consisted of two rooms rather than one. These findings indicate that both Euclidean and categorical distance are used during mental imagery. By themselves, these findings are still subject to alternative explanations by demand characteristics. In combination with the second measure of spatial distance, however, these alternative explanations are rendered very unlikely: The time needed to decide whether two designated objects were located in the same room or in different rooms showed the same effect of spatial distance, with response times affected both by path length and by the number of rooms. Moreover, we did not find any evidence for an interaction of Euclidean distance and categorical distance.

The fact that the effect of categorical distance was at least as strong as the effect of Euclidean distance is an unprecedented piece of information introduced by these experiments. Indeed, previous mental imagery researchers have not devoted much effort to investigating the effect of boundaries on the mental scanning process. The effect of categorical distance, to which the extra time needed to move across borders attests (here going from one room into another one by imagination), is a new finding that should inspire more research efforts. Should mental scanning be shown to be affected by the act of moving across interpolated objects or lines, this would bring an interesting support to the idea that part of the imagery processes may be accounted for by hierarchical theories of spatial representation (see McNamara, 1986, 1991).

Finally, our study also suggests differences between mental imagery and narrative comprehension. Despite perfect equivalence of the spatial layouts, former studies of text comprehension have not yielded effects of Euclidean distance on reading times or probe response times. Instead, only categorical distance affected these variables (Rinck et al., 1997). This discrepancy may be taken to suggest that during narrative comprehension, readers create only rough, categorical representations of spatial distance, whereas during mental imagery, they represent spatial distance at the more detailed level of Euclidean distance. Most likely, however, this conclusion is oversimplified: Even if readers often do not bother to create detailed spatial representations, they may very well be able to do so when it becomes necessary (see Rinck, in press). Therefore, a more promising explanation may be found in a recent suggestion to view comprehension as *mental simulation* (Zwaan, 2004). Indeed, results observed in mental scanning tasks may be thought of as caused by mental scanning (i.e., participants move their eyes across a mental layout of the museum) or, just as well, by mental simulation (i.e., participants imagine themselves walking through the museum). Similar differences would be those between a bird's-eye view of the layout and a first-person view of the layout or between survey knowledge and route knowledge (see Perrig & Kintsch, 1985; Taylor & Tversky, 1992). The current study was not designed to address this topic: The instructions favored the mental simulation of events, and many imagery instructions did not refer to motions, but the spatial distance effects may be explained by both mental scanning and mental simulation. It will be left to future researchers to differentiate between these accounts, and one way to achieve this may be to vary the speed of the imagined movement.[1]

If mental simulation is indeed the common mechanism in both mental imagery and narrative comprehension, it seems likely that the simulation may occur at varying levels of elaboration and detail. In some cases, it may be parsimonious, and the representation of spatial distance may be restricted to categorical distance, as in the experiments by Rinck et al. (1997). In other cases, the simulation may be elaborated enough to contain detailed information on Euclidean distances (as in the current experiments). As a consequence, the difference between text comprehension and mental imagery may turn out to be of minor importance. Instead, situational and individual factors (e.g., individual differences in goals and abilities) may have stronger effects on the level of detail represented in mental simulations. More research will be needed to test this hypothesis, and it will have to involve direct comparisons of different tasks, instructions, and participant groups.

[1] We thank Rolf Zwaan for suggesting this manipulation.

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Appendix

Sample Imagery Instructions and Test Probes Used in Experiment 1

Imagery instructions
You have entered the museum and you are in Hall 1. You walk from Hall 1 into Hall 3/2. There you look at the painting by Bosch. Then you move on to the Picasso painting. You are studying this masterpiece as well. Then you walk into Hall 6.
Critical motion instruction
You walk from Hall 6 into Hall 8/9.
Object pair test probe
Close-Object Pair: Goya–da Vinci Far-Object Pair: Magritte–Nolde Next, you move on into Hall 1. . . .

Note. Original materials were presented in German. Hall numbers varied according to the layout studied. The alternative numbers shown above denote the same hall.

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