Title
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A Method for Studying Representation of Action and Cognitive Distance

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Abstract

Past studies examining the effects of action on memory for route distance have overlooked the problem of the control of visual information. A new methodology was developed to investigate the involvement of action on the representation of route distance information in two experiments which eliminated the possible confounding effects of visual cues. In both experiments the number of turns was manipulated. Blindfolded participants learned new environments through verbal descriptions by imagining themselves walking in synchronization with metronome beats preset to match their natural walking speed. During turns, they were carefully moved. Following instructions, they performed an action at mid-route. Upon reaching the destination, their memories for the newly learned environments were tested through recall and measured again (with metronome beats representing footsteps). In Experiment 1 participants were exposed to the environment only once, and in Experiment 2 they were exposed to the environment twice. The results were consistent across the experiments and showed the influence of number of turns on remembered distances. Our data support the segmentation hypothesis with regard to the perception of the segment length and the influence of the number of turns on path distance estimates. However, our data point to a more parsimonious explanation in terms of body movement that triggers attentional processes which signal memory for events.

Introduction

When asked how far it is from one place to another there is much evidence that people do not give very accurate distance estimations. Investigations into the relationship between physical distance and cognitive distance have shown that the two differ. Furthermore, the differences between actual and cognitive distance are not random; cognitive distance is systematically distorted from the physical distance (Golledge, 1987).

The disparity in distance estimations has been explained as a function of the hierarchical organization of memory (e.g., Hirtle & Jonides, 1985; McNamara, 1986; Steven & Coupe, 1978), the organization of reference points (e.g., Sadalla, Burroughs, & Staplin, 1980), the modes of acquisition at learning (e.g., Thorndyke & Hayes-Roth, 1982), the contexts of learning (e.g., Gauvain & Rogoff, 1986; Taylor & Naylor, 2002), or the environment complexity (e.g., Sadalla & Magel, 1980; Thorndyke, 1981). Hence there is a disparate range of explanations for biases in distance estimation.

One possible explanation for bias in distance estimation, which has not been explored in detail, is that it may be a function of the actions we perform in the environment, and how those actions are cued on retrieval. This may provide a means of incorporating these multiple accounts of distance bias within a single unified framework. The view that cognition is grounded in the individual bodily interaction with the environment (e.g., Barsalou, 1999; Glenberg, 1997) is widely supported. Empirical evidence supporting the embodiment framework can be found across a range of domains. There is a tight coupling between visual perception and action. It has been shown that the representation of a visual stimulus generated from pictures or from purely linguistic descriptions can activate motor affordance, i.e., merely viewing an object, an image of an object, or hearing a description of an object results in the activation of the motor patterns necessary to interact with it (e.g., Richardson, Spivey, & Cheung, 2001; Tucker & Ellis, 1998). In language comprehension, understanding a sentence may call upon the same cognitive mechanisms as those used in planning and executing actions (Glenberg & Kaschak, 2002). It has also been shown that the representation of action or motor representation shares the same neural mechanisms as those that are responsible for the preparation and programming of actual movements (Decety, Jeannerod, & Prablanc, 1989). This evidence indicates that motor activation can occur as part of a cognitive process.

A number of studies have examined the effects of turning during route navigation. Sadalla and Magel (1980) found that paths containing several turns were perceived as being longer than paths of equivalent objective length with fewer turns, and the segmentation hypothesis has been used to explain this effect. The segmentation hypothesis claims that a right angle turn divides a pathway into segments and that the perceived lengths of the segments are combined to produce an estimate of total pathway length. Given two pathways of the same length but differing in the number of turns contained in each, the pathway with fewer turns will necessary have longer segments. These segments will be psychologically compressed to a greater extent than shorter segments (longer segments are underestimated relative to shorter segments). Therefore, the combination of a number of compressed segments will yield an underestimation of total pathway length. This underestimation will be greater for the pathway with fewer turns. However, this study does not separate out a range of possible explanations for these effects, such as visual cues, or the rate of motion (stepping up or down, or turning) that influence the perception of traversed distance (Hermann, Norton, & Klein, 1986; Rieser, Pick, Ashmead, & Garing, 1995). For example, Hermann et al. (1986) found that the size of the effect of turns on memory for distance is affected by the number and complexity of visual cues in the environment. Therefore, to examine whether action is implicitly part of cognitive processes, it is important to have strict control over the visual information that participants could perceive and extract from the environment during navigation, and the performance of action (walking and turning). A new methodology was developed that considered all these factors in order to allow us to adequately measure whether action exerts an effect on distance estimation during navigation. In the present study, we manipulated the influence of turns on traversed distances to assess more precisely the mental mechanisms that mediate why complex routes (with many turns) were estimated differently from less complex ones (with fewer turns).

Experiment 1

The methodology was designed to control for the confounding factors present in previous studies, while maintaining realism for participants. In order to do this, a blindfold methodology was developed where participants heard linguistic descriptions describing environments over headphones, and had to imagine themselves walking around the environment in time with a series of metronome clicks preset to control for speed of walk and size of step (number of clicks heard). The aim was for participants to listen and visualize the landmarks' descriptions (thus minimizing the risk of participants gauging distances by counting steps). The environmental descriptions were formulated as guided tours, and were read by a female colleague and tape recorded for use in the experiments.

The linguistic descriptions used were controlled for number of words and detail presented. Typically the environments included five landmarks (e.g., a school, a museum, a post-office, a bank, a library, etc.). Each landmark was described by specifying its physical or historical features. Following is an excerpt of a typical description of an environment, used in the study (landmarks are in bold): "*You are in a place called Charlestown, a typical New England town. Your starting place is Victoria Park. I am going to take you on a walk from Victoria Park to St John's Basilica. It is quite a nice walk with lots of things to look at on the way. You are now standing at the gate of a place called* ***Victoria Park****. Victoria Park is renowned for its formal and shrub gardens. They are of interest and beauty in all seasons. During summer, Victoria Park hosts a Folk Music Festival. … You are now at the entrance of a place called the* ***Central Library****. Built of silvery-grey stone, the front of the building has columns and triple arches with elaborated decoration at the tops. Inside the Library, there is an intricately carved oak staircase. You are standing directly in front of the book return box. Now I will let you post the book in the return box. You can actually feel the return box in front of you. So feel the box and post the book. …*".

To encourage participants to visualize only the described scenes, a blindfold was used in order to eliminate visual information that they could have gathered from the test laboratory. Furthermore, to examine the influence of action the actual walking was replaced by mental walking. A metronome pre-set to each participant's natural walking speed (stride length and frequency of stepping) emitted beats to simulate their walking rhythm. So instead of actually walking, participants heard a certain number of metronome beats, which corresponded to the exact measure of the distance to be traversed. When the distance was mentally traversed the metronome beats ceased. However, during the simulated navigation through the environment, participants performed an action (e.g., put an object into a box) which occurred at mid-route. This manipulation allowed us to determine whether there was any difference in the perception of distance before versus after performing the action on the representation of distance. Participants also experienced the change in angular displacement when he/she arrived at 90-degree turn in the mental walk. In this instance, they were rotated to face in the appropriate direction. Once participants reached the destination landmark, their memories for the newly learned environments were measured through recall. Participants were told that they were now at the starting landmark again and had to "walk" on their own towards the destination (still wearing the blindfold). They had to describe what they "saw" on the way, and to instruct the experimenter to engage/disengage the metronome to signal the start of the mental walk or to stop walking. The dependent variables were the remembered traversed distances, which were again measured by metronome clicks. The experimental arrangement is shown in Figure 1.

Figure 1: Arrangement during tests. The participant is on the right, with the experimenter behind her.

Environment Characteristics. Participants learned two routes (Route A and Route B). They were not aware that Route B was the mirror image of Route A.

As each route contained 5 landmarks, there were 4 paths in each (denoted P1 to P4). Each path measured 64 meters which meant the total route length measured (64 m x 4) 256 m. Ninety-degree turns divide a path into segments. Each route contained 11 segments. The segment lengths were fixed at 8, 12, 16, 24, 32, and 40 m. These distances were combined to make up the length of 64 m for each path. Figure 2 shows a schematic representation of one of the environments used in the experiment. Note that in Route A, P1, P2, and P3 contained 1 turn each followed by P4 with 4 turns; in Route B, P1 contained 4 turns followed by P2, P3, and P4 with 1 turn each. The performance of action occurred at mid-route (at the middle landmark); P1 and P4 were located at the outer positions of each route, while P2 and P3 were located at the inner positions of each route.

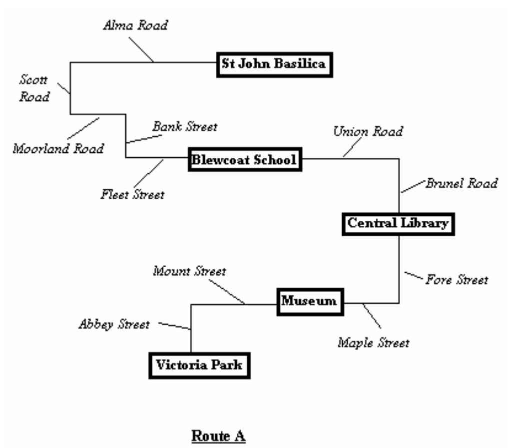

Figure 2: Configuration of Route A, in Experiment 1

Pilot Study. Before we ran the study, we tested the methodology on two pilot subjects in order to check whether they felt any discomfort during the test given that they had to wear a blindfold, and had to be physically turned during the testing procedure. However, the subjects commented that they were perfectly comfortable and relaxed during the test. We then proceeded to the first experiment using the new methodology.

Presentation. The study was presented to the participants as an investigation into people's memory for described places. They were told that they were going to listen to descriptions of imaginary walks through new environments, and were told that during the simulated walks they had to visualize the described landmarks. Additionally, they were asked to return a book or a parcel at some point en-route. The participants were not aware that their memory for distances was being tested.

Experimental Design. To examine the influence of action and the effect of number of turns on traversed distances, the experimental design used was a 2 route (Route A vs. Route B) x 2 position (inner vs. outer) x 2 action (before action vs. after action) within-subjects design.

Participants. Twenty-nine undergraduate students agreed to participate in the experiment in exchange for course credit. They were between 18 and 35 years old (mean age = 20.50, SD = 4.80). By agreeing to participant in the experiment, they were aware that they would wear a blindfold during the test.

Procedure. Participants were tested individually in a session lasting about 45 minutes. Initially, participants were instructed to walk round the room (following a pre-designated path) at their own natural walking speed so that step length and speed of walk could be established. Next, they were asked to put on the blindfold and headphones, and to stand comfortably at the centre of a circle marked on the floor. The experimenter familiarized the participants with the turning procedure: she spun the participant around on the spot, finishing by positioning him/her facing a box that was sitting on a table. At this time, the experimenter gave the participant the book or the parcel to carry with him/her. Then the participants were instructed to visualize the landmarks when they heard the descriptions, and to imagine walking in synchronization with the metronome clicks, and to stop imagining walking when the metronome ceased clicking. The experimenter then started the tape player and both listened to route descriptions through headphones. At the appropriate times, the experimenter stopped the player and engaged the metronome to implement the mental walking. During turns, the experimenter intervened by physically rotating the participants on the spot. Note that all turns were 90 degrees turns. At mid-route, participants performed the dispatch task as instructed, i.e., he/she extended his/her arm to reach the box, touched it to find the slot, and then dropped the objects into the box. Once the destination was reached, the experimenter spun the participant around again and positioned him/her in front of the box. Still blindfold, the participant's route memory was tested through recall. After the recall of the first route, the second route was immediately presented which was followed straight away by the recall.

For the recall, participants were told that they were taken back to the starting place from which they had to re-walk the routes. They were asked to describe back as accurately as possible what they "saw" en-route. They had to tell when they wanted to walk away from the landmarks and when they wanted to stop walking, so that the experimenter could engage and disengage the metronome. At turns, they had to rotate themselves on the spot and to indicate verbally the direction of turns. Once it was established that participants understood the recall instructions, the experimenter switched on the recorder that participants carried with them.

Data Treatment. The participants' recalls were transcribed. Then we proceeded to check the order of landmarks recalled by the participants. In order to ensure that participants had a good understanding of the environments they learned, only responses with the correct sequence of landmarks were used in the analyses.

Data were obtained by first translating the number of metronome clicks (= steps) into traversed distances expressed in meters. The accuracy of turns with regard to amplitude and direction was not recorded in the present experiment.

Results

Responses from 13 participants (45%) were excluded. Twelve of these produced incorrect sequences of landmarks for one or both routes, and the remaining participant was eliminated because of poor English. Responses from 16 participants were used in the analysis (55%).

To check whether participants were not gauging distance by counting the number of steps a correlation between the total number of steps to walk Route A and Route B and the re-walked distances of both routes across participants was performed. The results showed no significant correlation, indicating that participants were not counting clicks and remembering the number of clicks on recall. As both Route A and Route B contained 11 segments each, in total there were 22 segments. For each segment, we averaged the remembered distances across participants in order to examine the correlation with the corresponding actual distances. We found an overall significant correlation between actual and remembered distances, $r_{(22)} = 0.68$, $p < 0.001$ (1-tailed), which indicates that longer segments were associated with remembering walking longer distances on recall. To examine the influence of action and the effect of number of turns on traversed distances, a 2 route (Route A vs. Route B) x 2 position (inner vs. outer) x 2 action (before action vs. after action) within-subjects ANOVA was performed on path distances. The results of the 3-way ANOVA are displayed in Table 1.

Table 1: Results of the 3-Way ANOVA on Path Distance Estimation in Experiment 1.

Source	df and F value	MS (error)	Significance
Route (R)	$F_{(1, 15)} = 1.89$	442.53	ns
Position (P)	$F_{(1, 15)} = 8.88$	1922.00	**
Action (A)	$F_{(1, 15)} = 0.93$	94.53	ns
R x P	$F_{(1, 15)} = 0.90$	105.12	ns
R x A	$F_{(1, 15)} = 0.85$	195.03	ns
P x A	$F_{(1, 15)} = 0.30$	128.00	ns
R x P x A	$F_{(1, 15)} = 8.44$	430.13	*

Note. ns: p > .05; *: p < .05; **: p < .01

No main effects of route, or action were found. However, there was a main effect of position on remembered path distances. Overall, participants remembered walking significantly longer distances on the outer paths (one of which contained 4 turns) than on the inner paths (which contained one turn). There was also a significant 3-way interaction between route, position, and action on remembered path distances. Follow up analyses indicated that in Route A, after the performance of action the outer path (i.e., P4 contained 4 turns) was remembered as being significantly longer than the inner path (P3 contained 1 turn), $F_{(15)} = 6.16$, $p < 0.05$. In Route B, the reverse was the case; before the performance of action the outer path (P1 contained 4 turns) was remembered as being significantly longer than the inner path (P2 contained 1 turn), $F_{(15)} = 6.64$, $p < 0.05$. This result confirmed that the influence of number of turns was a robust effect on remembered distances.

Discussion

We developed a new procedure in order to allow us to adequately measure whether action exerts an effect on distance estimation. During the experiment, none of the participants expressed any discomfort during or after the task, indicating that the methodology was appropriate.

That said, there was a large dropout rate (45%) due to participants not being able to reproduce the landmarks in the correct order (or to remember all the landmarks completely). This may have been because the task was too difficult, or because participants were exposed to the environment only once.

Despite the high dropout rate, we found that within the same routes, distance estimation was influenced by the number of turns contained in a path; paths containing four turns were remembered as being longer than paths with one turn. This result is in line with evidence from other studies (Sadalla & Magel, 1980), but with more control over visual information and action. Our procedure allowed us to observe the effect of number of turns on the same route through auditory simulated navigation, while Sadalla and Magel (1980)'s result was on separate paths, and involved actual walking. However, taking together both studies indicate that the influence of number of turns on memory for distance is a robust effect.

The absence of the effect of performing an action may be due to the salience of the action itself. The movement of dispatching (dropping) an object into a box may be perceived as a simple and routine activity therefore was not salient enough to exert an effect on spatial representation. A sequence of more pronounced movements to perform the dispatch task may make the action more memorable. For the moment, we were concerned by the high dropout rate. For that reason, in Experiment 2 we exposed participants to the same environments twice before their memories were tested using exactly the same methodology as in Experiment 1.

Experiment 2

Method

The method used was the same as in Experiment 1, except that this time participants were exposed to each environment twice before recalling routes.

As in Experiment 1, participants learned two different routes (Route A and Route B), and then they had to reproduce each route trip in free recall. Route A and Route B were presented to participants in counterbalanced order.

Participants. Twenty-three undergraduate students agreed to participate in the experiment in exchange for course credit. Participants were between 18 and 46 years old (mean age = 24.17, SD = 7.84). They were tested individually.

Procedure. The procedure was exactly the same as in Experiment 1, however here participants were guided through each route twice before their memories for each route were tested through free recall. The tests lasted about one hour.

Results

As in Experiment 1, to be included in the analyses participants' responses must show the correct sequences of landmarks in both routes. Responses from 18 out of 23 participants (78%) were used in the analyses. Responses from 5 participants (22%) were eliminated (4 incorrect sequences of landmarks, 1 poor quality recording). The exposure to the environment twice seemed to work as the rate of data inclusion has much improved, although there is still quite a high rate of exclusion.

On average, we found that short distances were overestimated, whereas longer distances were underestimated. The overall correlation between actual and remembered distances was highly significant, $\underline{r}_{(22)} = 0.68$, $\underline{p} < 0.001$ (1-tailed). This result indicates that if the actual distances were longer, participants remembered walking longer distances as well.

To examine the influence of the number of turns, position, and action on path distance estimates, a 2 route (Route A vs. Route B) x 2 position (inner vs. outer) x 2 action (before action vs. after action) within-subjects analysis of variance was performed on path distance estimates. There were no significant effects of route, or action. However, there was a main effect of position on path distance estimates. Overall, participants walked significantly longer distances at the outer paths (one path contained 4 turns) than the inner paths (1-turn paths). There was a significant 2-way interaction between route and action; before action, remembered distances were shorter in Route A than in Route B; however after action, remembered distances were larger in Route A than in Route B. This effect was observed because of the influence of number of turns. There was also a significant 3-way interaction between route, position, and action. As in Experiment 1, the follow up analyses indicated that in Route A, after the performance of action the outer path (i.e., P4 contained 4 turns) was remembered as being significantly longer than the inner path (P3 contained 1 turn), $\underline{F}_{(17)} = 4.09$, $\underline{p} = 0.05$. In Route B, the reverse was the case; before the performance of action the outer path (P1 contained 4 turns) was remembered as being significantly longer than the inner path (P2 contained 1 turn), $\underline{F}_{(17)} = 9.41$, $\underline{p} < 0.01$. This result confirmed the robust effect of number of turns on remembered distances; the inner paths (P2 and P3) were not remembered significantly differently from one another.

Discussion

The fact that participants were exposed to the environments twice in order to acquire route knowledge substantially improved the data collection. Although the rate of exclusion was still high (22%) suggesting that some participants' memories for routes were imprecise, the majority of participants produced the landmarks in the correct order, and therefore distance estimates could be analyzed.

The results replicated those in Experiment 1. As expected, the effect of number of turns was also observed in this experiment; paths with more turns were remembered as being longer than paths with fewer turns. The absence of the influence of action may be due to the salience of the action itself. A more pronounced sequence of movements to perform the dispatch task may make the performance of action more memorable thereby the prediction of a difference between remembered distances before and after the performance of action would stand more of a chance of being found if present.

General Discussion

The new procedure was developed with the aim of controlling confounding factors, such as visual cues and the speed of walk in order to adequately investigate whether action exerts an effect on distance estimation during simulated navigation.

To begin with, in general during tests participants claimed they felt comfortable and relaxed with the task, which indicated that the methodology was an appropriate and sensitive procedure, especially given that participants had to wear a blindfold for the whole duration of the test that lasted about one hour. However, despite the relatively high dropout rate, the data we collected across both experiments indicated nevertheless that the methodology was successful. Future studies could present the environment a third time, which might improve the inclusion rate further.

Let us now consider how our data fit with current theories of environmental knowledge. Our results are in line with the segmentation hypothesis with regard to the perception of the segment lengths and the influence of the number of turns on path distance estimates. However, we found the same effect of number of turns on remembered distances without actually traversing any distance. Our data actually point to an interpretation in terms of attention processes that signal memory for events. Participants heard the metronome clicks representing their footsteps during mental walks. It was clear that they had internalized distance and direction as well as turns information for use during recall that had enabled them to get from the starting landmark towards the final destination. As they were not walking any distance, they seemed to have been encoding the action of turning. In the absence of direct visual information, the body movement triggers the retrieval process; i.e., the participants' attention would focus on memory for events (actual turning). However, this form of representation is available for limited periods only; as time went on, memory faded and decayed (Thompson, 1983). The attention process then must be shifted in order to attend to the next event that came to mind. To proceed still further, the attention process had to be re-initialized. When walking naturally one average footstep measures about 70 cm, and there are two footsteps forward per second. Therefore, it will take 10 sec to walk 14 m. It is not surprising in terms of the attentional process that people remember only a certain distance (14 m) given that they can focus their attention only for the first 10 sec during retrieval. The fact that participants remembered walking longer distances in paths containing 3 turns than paths containing 1 turn corresponded to the fact that they were actually moving (turning) more often in paths with several turns as well. Consequently, the more turns in a path the more attention shifts were required and the longer the perceived distance. The cognitive mechanism uncovered in the present study is different from that of the segmentation hypothesis. We attributed the fact that paths with more turns were remembered as being longer than paths with fewer turns to the attention shifts during the retrieval process, and suggested that the function of body movement was to re-initialise the retrieval process.

Although the new procedure permits a more precise examination of processes involved in spatial judgment, work needs to be done regarding the large drop out rate. Maybe repeating the simulated walk three times would improve data collection. Additionally, the influence of action at the midpoint would stand more of a chance to be found if present by making the action more pronounced (through more extensive turning or walking on the spot).

More importantly, further work needs to be done in order to establish whether our results can be generalized. For example a comparison between the present study and a study where actual walking takes place is desirable.

Despite these limitations, the new procedure has allowed control over action and visual information during testing, and provides a means for future investigation of a range of possible action manipulations that have hitherto evaded controlled experimental procedures. It also provides important indication that basic processes underlying mental distance estimation seem to persist even in rather extreme sensory deprivation conditions.

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