Distortions in geographical judgment: The relationship between hierarchical organization and rotation

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INTRODUCTION

One of the ways to learn about how people remember spatial relations such as directions and distances in a large-scale geographical environment is by studying the *systematic distortions* that appear when people are asked to evaluate these relations. Distortions resulting from *rotation* and *hierarchical organization* are considered to stem from remembering the geographical entity relative to a frame of reference or to the presence of a higher-order geographical entity, correspondingly.

Rotation errors occur when the axes of a remembered figure of an area are merged with an objective external frame of reference, such as the earth's coordinates (Tversky, 1981). Errors due to hierarchical organization are expressed when the relative direction between geographical locations is distorted as a result of the perceived direction of super-ordinate spatial categories (Stevens & Coupe, 1978). Thus, rotation and hierarchical organization are representations, or principles by which spatial memory is constructed, as well as heuristics that people use when spatial orientations are difficult to remember.

It is reasonable to assume that these representations of spatial information, and the systematic errors they cause, may be operative in the same geographical area (Tversky, 1992, 1993). For example, Tversky stated that people can use categorical (i.e. hierarchical) information for judging spatial relations instead of, or in addition to the Euclidean information in a map or environment (Tversky, 1992, p.133). Huttenlocher et al. (1991) as well as Friedman and Brown (2000) have proposed that spatial information is basically presented at both an item level and category level, and then, accurate information about the item level (e.g. city) can be related to an external frame of reference but at the same time it can likewise belong to a super-ordinate category (e.g. region). Moreover, this dual representation is suggested as a source of spatial memory distortions (Huttenlocher et al., 1991; Werner and Diedrichsen, 2002; Sampaio and Wang, 2009). There is also evidence that many errors in geographical judgment may occur because super-ordinate regions are themselves referenced to another, external frame of reference, such as the earth's coordinates (Friedman & Brown, 2000; Friedman et al., 2002; Friedman & Montello, 2006). Consider the North American—European alignment error found by Tversky (1981), Friedman and Brown (2000) showed that not all participants in their experiments positioned Europe as south of all of North America; rather, the North American and European continents were subjectively divided into distinct sub-regions (e.g., northern vs. Mediterranean Europe), with the participants not distinguishing the locations of cities within the sub-regions.

However, it is not clear yet how and when these representations of spatial information interact in spatial memory and/or in judging spatial relations. The aim of the research presented here is to investigate how the systematic distortions that resulting from rotation and hierarchical organization interact in geographical judgment. More specifically, our aim was to clarify how these representations influence each other when the potential exists for both to be active when judging geographical locations. Three research questions were formulated on this basis: (1) Does one representation have priority or dominance over the other? (2) Do they have additive effect (when they act in the same direction)? (3) Do they have a subtractive effect (when they act in opposite directions)?

METHODOLOGY

In this research we chose to use artificial maps as the device enabling us to examine the relationship between the rotation and hierarchy. We conducted five experiments in order to test the different conditions of this relationship. The maps was designed by modifying and integrating the artificial maps used by Tversky (1981, p.417) to test the rotation distortion and the artificial maps used by Stevens & Coupe (1978, p.430) to test the distortion due hierarchical organization. These maps, shown in Figure 1, have the potential to express, either independently or simultaneously, the respective representations. The size of each map was 6 x 9 cm. Each map contained four cities, indicated by letters. In all the maps, the pair of cities c-d was the critical pair, with the rest functioning as fillers. The direction "north" was also indicated on each map.

In each of the five experiments, the participants were asked to estimate the directional relationship between pairs of cities on only one of the five maps (numbered 1-5, respectively). Each experiment included 18 different participants or a total of 90 participants. The participants were allowed to study the map for 1 min and then, after the maps are collected, were asked to estimate the direction between all the possible pairs of cities in different order. We used the "direction circle" or "compass direction" method, as applied by Stevens and Coupe (1978) and Tversky (1981) to estimate the directions. When using this method, participants are asked to estimate the relative direction of selected pairs of locations as follows: The participants imagine that one city lies in the centre of a circle. He or she then draws a line from the centre of a 2.7 cm radius circle to the perimeter of the circle that represents the direction of the second city. Each "direction" task is presented on a separate sheet of paper of size A4. Figure 2 illustrates the method. The experiments were conducted as follows:

Experiment 1: A case where the spatial relationship has the potential to activate rotation (Map 1, Figure 1; this map is identical to Tversky's map). In this condition, direction estimation is expected to be systematically distorted counter-clockwise as a result of remembering the directions relative to the external frame of north, south, west and east.

Experiment 2: A case where the spatial relationship has the potential to activate hierarchy (Map 2). To construct Map 2, we modified Map 1 by shifting it counter-clockwise by 15° in order to fit the axes of the figure to the axes of the frame and by dividing the map's space into two regions (Alfa and Beta), indicated by a border line. The border line between the regions passes is equally distanced (by 0.5 cm.) from the cities c and d. In this map, the direction of c-d does not fit the direction of the super-ordinate regions. The direction of c-d as indicated by the participant is expected to be distorted counter-clockwise as a result of the direction of the super-ordinate regions.

Experiment 3: A case where rotation and hierarchy may operate in the same direction (Map 3). We constructed Map 3 by taking Map 1 (conditions of rotation) and adding a border creating two regions where the direction of c-d does not fit the direction of the super-ordinate regions, Alfa and Beta (conditions of hierarchy). Under these conditions, the participant is expected to distort direction of c-d counter-clockwise as a result of both rotation and the general direction between the super-ordinate regions.

Experiment 4: A case where the spatial relationship has a potential for activating rotation and hierarchy in opposite directions (Map 4): To move from activation in the same direction to activation in the opposite direction, we modified Map 3 by changing the location of the border between the regions and the location of city d. As a result, the participant is expected to distort the direction of c-d counter-clockwise due to the effect of rotation and to distort the direction of c-d clockwise due to the effect of hierarchy (the direction Alfa-Beta).

Experiment 5: This experiment also contains the potential for activating rotation and hierarchy in different directions (Map 5). However, unlike Experiment 4, the hierarchical representation in this experiment has no potential to cause a distortion. This condition enables us to explore if the rotation distortion will occur not only in relation to cities but also to super-ordinate regions. To construct Map 5 we modified Map 3 by changing the location of the border between the regions in order to fit the direction of c-d to the direction of the super-ordinate regions.

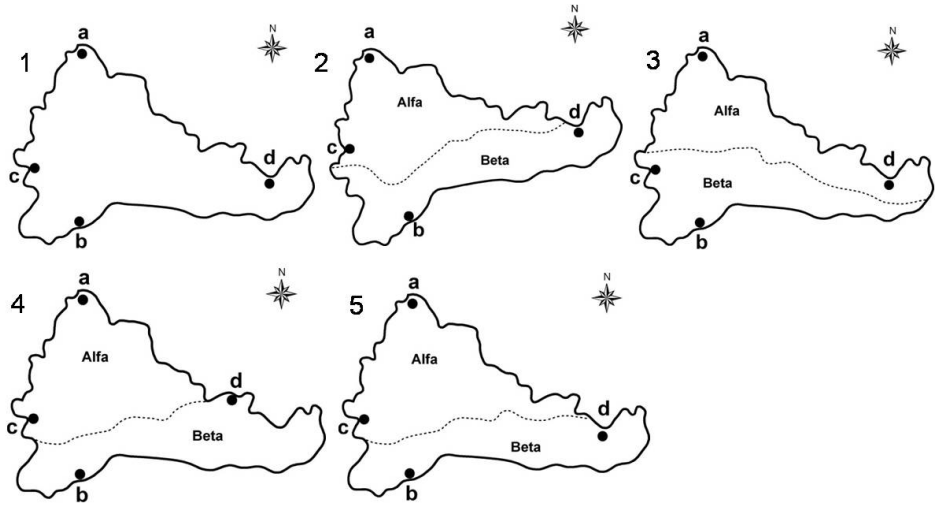

Figure 1: Artificial maps used to examine the relation between systematic distortions resulting from rotation and hierarchical representation; Map (1) potential for activation of rotation; Map (2) potential for activation of hierarchy; Map (3) potential for activation of rotation and hierarchy in the same direction; Map (4) potential for activation of rotation and hierarchy in opposite directions; Map (5) potential for activation of rotation and hierarchy in different directions. The pair of cities c-d is the critical pair; the rest are fillers.

Instructions (in Hebrew):
Imagine that city c lies in the centre of the circle and that you are in city c. Draw a straight line from city c in the direction of city d. Make sure that the line reaches the edge of the circle.

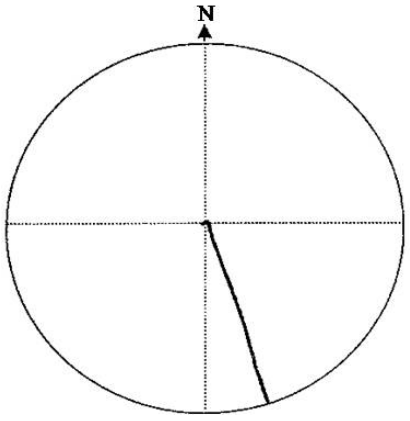

Figure 2. An example of one participant's completion of a "direction" task

RESULTS

Summary statistics for the direction estimation of the pair of cities c-d in experiments 1-5 are presented in Table 1. In Experiment 1, where the potential to activate rotation was present, the estimated direction of c-d was systematically distorted counter-clockwise (m=-16.1°, p<0.015). These results are expected and in line with the results obtained by Tversky (1981). In Experiment 2, where the potential for distortion due to hierarchical representation was present, the results show that estimation of the direction of c-d is systematically distorted clockwise (m=25.2°, p<0.021), based on the directions between the super-ordinate regions, Alfa and Beta. The findings of the two experiments show that the conditions of the geographic environments presented in Maps 1 and 2 caused distortions solely of either rotation or hierarchy, respectively.

Table 1: Summary statistics for direction estimation of the pair of cities c-d (t-test, two-tailed)

Experiment No.	True direction	Mean estimated direction	Mean distortion*	t	P	N**
1	95	78.86	-16.14	-2.812	0.015	14
2	85	110.21	25.21	2.618	0.021	14
3	95	79.94	-15.06	-3.984	0.001	16
4	85	97.23	12.23	2.314	0.034	17
5	95	98.19	3.19	0.555	0.587	16

* Mean estimated direction – real direction; a negative difference (-) represents a counter-clockwise error; a positive difference (+) represents clockwise error.

** To avoid effect of disorientation errors, the direction estimations that differed by at least 90° from the true direction were excluded from the statistical analyse.

Unlike Experiments 1 and 2, there were conditions for the two representations to be active in the remaining three experiments. In Experiment 3, where there was a potential for rotation and hierarchy both to be activated in the same direction (counter-clockwise), the results clearly revealed that the joint effect of these two representations caused a more significant counter-clockwise distortion (m=-15.06°, p<0.001) when compared to a case where each representation acted exclusively. Hence, the findings indicate that the joint activation of rotation and hierarchy has an additive effect. It should be noted that the additive effect is expressed not in the extension of the distortion but in its significance and consistency: Only 1 out of 18 participants estimated the direction clockwise (contrary to the direction of rotation and of the super-ordinates)!

In Experiment 4, rotation and hierarchy were activated together but here they operated in opposite directions – the direction of c-d was expected to be distorted counter-clockwise due to the effect of rotation and clockwise due to the effect of hierarchy. The results show that in this case there was a significant systematic clockwise distortion, as expected under conditions of hierarchy (m=12.23°; p< 0.034). This implies that when rotation and hierarchy may potentially cause distortions in opposite directions, hierarchy has priority. Though the distortion is smaller relative to the case where hierarchy operates exclusively (Experiment 2), the subtractive affect stemming from the simultaneous activation acts mainly on rotation.

In Experiment 5, rotation and hierarchy were likewise activated in different directions. In this case, however, the direction of the cities c-d matched the direction of the super-ordinate regions, i.e., c was north of d as region Alfa was north of region Beta. Hence, no error was expected to result from hierarchy, only from rotation. The results of this experiment clearly indicate the subtractive effect and

dominance of hierarchy relative to rotation — the participant's estimate became more accurate and the distortion due to rotation was fully prevented (m=3.19°; p=0.59). Hierarchical representation of the examined geographic space may perhaps have helped the participants remember the accurate direction of the cities and reduce errors in estimation of spatial relations. With respect to the results of Experiment 4, it means that the direction between geographic locations and that between the regions themselves were not distorted as a result of rotation when there are conditions for hierarchical representation.

CONCLUSIONS

Our investigation of the relationship between the distortions of rotation and hierarchy produced several findings. First, when such distortions can potentially take place in the same direction, they have additive effects, expressed in much more significant systematic distortions. Second, when they act in opposite directions, the distortion due rotation prevented while the systematic distortion due hierarchy continues to operate, but slightly less intensely. This means that rotation and hierarchy distortions have asymmetric subtractive effects: hierarchy has clear priority. Hierarchical representation, according to the findings of this research, has dominance not only through the distortion stemming from it, but also due to the help it provides in avoiding the errors that result from rotation.

Based on these findings, we can conclude that the rotation distortion caused by remembering the direction between geographical locations relative to an external frame of reference can be prevented when conditions for hierarchical representation are also present in the same geographical environment. The priority or dominance of hierarchical or categorical representation observed generally corresponds with findings reported from empirical studies on judging spatial relations in real large-scale geographical environments (e.g. Friedman et al., 2002; Friedman & Montello, 2006).

Further research is needed to confirm the conclusions of the current study by investigating the operation of the two kinds of systematic distortions in different conditions. Based on the data and the findings of the current research, we plan to test conditions of different degrees of rotation and condition containing representation of an additional hierarchical level, that is, the division of each region into distinct sub-regions. Empirical research in real environments containing conditions for both types of systematic distortions would contribute greatly to our understanding of the relation between them.

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