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Are people with high and low mental rotation abilities differently susceptible to the alignment effect?

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Abstract. We investigated whether the alignment effect (Levine et al, 1982 *Journal of Experimental Psychology: General* **111** 157 – 175) is influenced by mental rotation abilities. In two experiments, groups of undergraduate students with high and low performance in mental rotation tasks were required to study either schematic (experiment 1) or more complex (experiment 2) maps, and to perform a number of pointing tasks adopting a perspective which could be aligned, misaligned (45°, 135°), or counteraligned (180°) with the perspective assumed during learning. Cognitive styles in spatial representation have also been considered. Results of experiment 1 show that people with low performance in mental rotation tasks prefer to adopt a representation of space focused more on landmarks. Their performance in the pointing tasks depends on the alignment conditions, with more errors in the counteraligned condition followed by the two misaligned and aligned ones. In contrast to this, high-ability mental rotators prefer survey and route spatial representations and are affected only by the aligned and non-aligned conditions. In the second experiment, practice was studied as a function of mental rotation and alignment. The group high in mental rotation ability was found to be free from the alignment effect in the pointing tasks performed after the final of four learning phases.

1 Introduction

The question how people mentally represent spatial knowledge acquired from maps has been intensively studied during the last decades, with particular emphasis on the perspective assumed in mental representation compared to that originally assumed by the map. To date, several studies have demonstrated that, in the creation of mental representations of maps, people maintain the perspective adopted during learning (Levine et al 1982; Presson and Hazelrigg 1984). Empirical support for this assumption comes from the 'alignment effect', first studied by Levine et al (1982). For example, Roskos-Ewoldsen et al (1998) asked the participants to memorise schematic maps similar to those shown in figure 1.

Immediately after the learning phase the participants had to imagine being at one of the map's locations whilst pointing to another. When participants had "to imagine being in 1, facing 2, and pointing at 3" (aligned condition) they did so more accurately than when they were required "to imagine being in 2, facing 1, and pointing at 3"

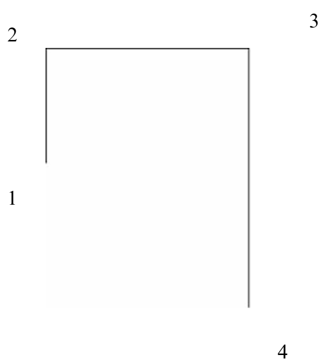

Figure 1. An example of schematic maps similar to those presented in Levine et al (1982).

(counteraligned condition). The finding that the performance in the counteraligned condition is worse than that in the aligned condition has been named the 'alignment effect'.

The alignment effect is generally thought to be quite consistent, even though several studies have shown that it can be affected by a number of factors. Among these, the size of the spatial configuration plays an important role. When a small spatial configuration is used, the alignment effect is more likely to occur (Presson et al 1989; Roskos-Ewoldsen et al 1998; Rossano and Warren 1989). However, it also appears, although less consistently, with large spatial configurations (Evans and Pedzek 1980; Presson et al 1989; Presson and Hazelrigg 1984). The possibility of experiencing spatial configurations from different viewpoints can explain this difference. In fact, when spatial configurations are large enough to allow participants to navigate through them and to experience multiple perspectives, their representations become more flexible and less perspective-dependent. In this case, the alignment effect is weaker (Thorndyke and Hayes-Roth 1982). Féry and Magnac (2000) found that voluntarily locating new spatial cues in extracorporal frames increases flexibility in orientation and, as a consequence, decreases the alignment effect. In their experiment, two groups of participants were required to learn the location of five objects, following instructions which emphasised either an egocentric or an allocentric frame of reference. Both groups then had to perform a number of directional judgments from imagined positions which could be aligned, counteraligned, or misaligned (60° and 120°) in relation to the perspective adopted during learning. The analyses of pointing times and accuracy showed that, unlike the egocentric group, the allocentric group was unaffected by the alignment effect.

Nori and Giusberti (2002, experiment 2) found that individual cognitive styles in spatial representation play a role in determining the occurrence of the alignment effect. They used different cognitive tasks to select three groups of participants, each characterised by a different cognitive style in spatial representation. Following Siegel and White (1975) and Pazzaglia et al (2000), each group was characterised by a different preference for either visual, route, or survey spatial representations. Visual representation focuses on salient landmarks and does not maintain the spatial features of the environment; route representation uses an egocentric frame of reference and focuses on the representation of routes connecting salient landmarks, whilst a survey representation adopts an allocentric frame of reference using global reference points. Their results indicated that only participants with a preference for a visual cognitive style showed an alignment effect. This was interpreted as a demonstration that survey and route participants used more effective, perspective-free encoding processes. However Nori and Giusberti's study does not answer the question: "Why do some participants spontaneously adopt spatial strategies that leave them free from the alignment effect?". Answering this question may help to clarify the cognitive mechanisms which underlie spatial learning and spatial representations.

Rossano et al (1995) assessed the extent to which individuals are susceptible to the alignment effect. In accordance with previous studies the alignment effect clearly emerged when the average scores of the entire sample were considered (Presson et al 1989; Presson and Hazelrigg 1984; Rossano and Warren 1989). However, the alignment effect was not so consistent when performance was analysed separately for each individual, 30% of participants being equally accurate in the aligned and non-aligned conditions. Nor did the percentage of people free of the alignment effect change when less schematic, more ecological, maps were used (Rossano et al 1995). These results show that individual differences are crucial in determining the occurrence of the alignment effect. However, Rossano et al's (1995) procedure did not explain why a number of people did not show an alignment effect. The authors stated that further investigations were necessary in order to decide between the various plausible interpretations of their results. One such interpretation, in line with that advanced by Nori and Giusberti (2002), suggests that the subgroup free from the alignment effect may use more effective encoding processes when learning the environment and maps. An alternative interpretation is that the no-effect subgroup may have been more effective at manipulating the stored map image. More specifically, the mental-rotation ability was supposed to be critical to the formation of a more flexible map representation. Regarding this, Rossano et al (1995) stressed the fact that the subgroup free from the alignment effect was largely composed of males, and several literature reviews on individual differences and spatial abilities suggest that males are more successful than females in mental-rotation tasks (Linn and Petersen 1985; Voyer et al 1995).

Differences in mental-rotation abilities may have also been a significant factor in the results obtained by Nori and Giusberti (2002), since we cannot exclude that participants with a survey and/or route preference also show greater mental-rotation skills. This was the assumption in the study by Pazzaglia and De Beni (2001), where participants with a survey preference in spatial representation were also shown to be better at performing the mental rotation task (MRT; Vandenberg and Kuse 1978), perhaps suggesting that, for a survey representation to be elicited, a superior ability in the maintenance and manipulation of spatial information is required.

If mental rotation (MR) is truly critical in determining the occurrence of an alignment effect, we would expect people with different MR abilities to perform differently in aligned and non-aligned pointing tasks. In fact, a superior MR ability would allow better manipulation and processing of stored spatial information. In order to test this hypothesis we compared the performance of people with different levels of MR abilities both in aligned and non-aligned pointing tasks. Two experiments were carried out to test the hypothesis and simultaneously compare the use of different materials and procedures. In the first experiment, schematic maps, similar to those used by Levine et al (1982), were presented to participants. Following the guidelines in Rossano et al (1995, experiment 2) more complex and ecological maps were used in experiment 2 to investigate the influence of distinct learning sessions in determining the occurrence of an alignment effect. In fact, the more complex map was presented during four distinct learning sessions and, after each session, participants were required to perform several aligned and non-aligned directional judgments.

Materials and procedures were similar to those in Rossano et al (1995). Participants had to learn a number of schematic maps (experiment 1) or a more complex map (experiment 2) from a fixed perspective. At the end of the learning phase for each map, they had to perform different directional judgments, imagining being in a specific location and facing a second one. Perspectives adopted in the testing phases could be either aligned, counteraligned, or misaligned with the perspective assumed during learning. Response times (experiment 1) and angular errors (experiments 1 and 2) for each condition in the directional judgment tasks were recorded.

In our experiments, participants were split into two groups, one with low and one with high MR ability. First, we intended to verify if the two groups differed in their preference for adopting survey versus route versus visual representations of space (experiment 1). Second, we expected the high MR ability group to be more accurate than the low MR ability group in performing the pointing task, given the former's superior ability in manipulating mental images of learned maps. In relation to the hypothesised influence of MR ability on the alignment effect, our expectations were that high MR ability individuals were less likely to be influenced by aligned, counteraligned, and misaligned conditions in the pointing tasks and that the proportion of individuals showing an alignment effect would be lower in the high MR ability group than in the other group. In the second experiment, the effect of the map learning time on the occurrence of the alignment effect was tested. Given previous studies on the mental models of spatial descriptions (Bosco et al 1996; Pazzaglia et al 1994; Perrig and Kintsch 1985; Taylor and Tversky 1992), where representations of repeatedly experienced stimuli were shown to be independent of perspective, we expected the alignment effect to decrease from the first to the final of four map-learning phases and that this trend would be particularly strong in the high MR ability group.

2 Experiment 1

2.1 *Method*

2.1.1 *Participants.* The participants were fifty-two undergraduate students (nine males, forty-three females) split into two groups: a high MR ability group composed of twenty-two participants (five males, seventeen females) and a low MR ability group composed of thirty participants (four males, twenty-six females). The two groups were selected from a sample of one hundred and sixty-seven undergraduate students on the basis of their performance in the mental rotation test (MRT) by Vanderberg and Kuse (1978). The MRT consisted of 20 items, each composed of a target 3-D stimulus followed by four test stimuli. Participants had to choose among the test stimuli the two that were identical to the target but shown from a different perspective. The participants had to perform the test within a 10 min time limit. The score was the sum of items in the whole task in which the two stimuli identical to the target were correctly chosen. The forty-two participants performing equal to, or lower than, the 25th percentile (score = 4) were considered within the low MR ability category whilst the forty-three participants performing equal or better than the 75th percentile (score = 10) were considered to be in the high MR ability range. Fifty-two of the selected participants volunteered to participate in the experiment. A subsample of fifteen low MR ability and eighteen high MR ability participants was administered a standardised reading comprehension test (Cornoldi et al 1991), in order to exclude more general cognitive differences between the two groups. In this test, participants were required to silently read two short texts and to answer ten multiple-choice inferential questions for each of them. Differences between the two groups in reading comprehension were not significant ($t_{31} = 0.90$, $p = 0.37$).

2.1.2 *Materials.* Six schematic maps were used in the present experiment, created according to the guidelines in Levine et al (1982) and Rossano et al (1995). Each map depicted a simple line drawing containing three segments and four points (see figure 2 for an example of a map). The maps were drawn in black on A4 sheets of paper. The 2 – 3 line segment of the drawing always extended from the 1 – 2 line segment at either a 90°, 45°, or 135° angle and the 1 – 2 and 3 – 4 line segments were always parallel to each other.

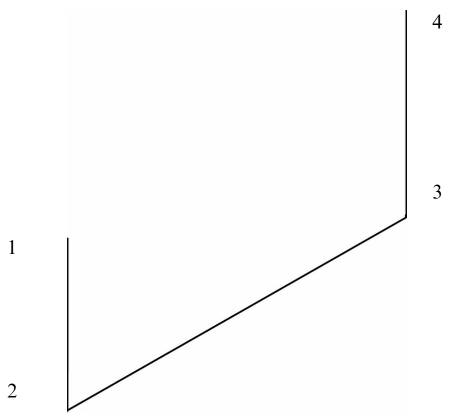

Figure 2. An example of schematic maps used in experiment 1.

A protractor with a diameter of 140 cm marked in 5° increments from 0° to 360° was used to register responses in the directional-judgment tasks, following the procedure described in section 2.1.3.

The questionnaire on spatial representation (QSR; Pazzaglia et al 2000) is a self-rate scale (see Appendix 1) which comprises 11 items on different spatial abilities: general sense of direction; knowledge and use of cardinal points; outdoor and indoor orientation abilities; and preference for survey, route, or landmark-centred representations. In particular, the questionnaire allows for the scoring of the three different spatial representation styles, ie landmark-centred, route, and survey, respectively, derived from the summed scores of items 3b + 4c, 3a + 4b, 3c + 4a. The psychometric characteristics of the QSR, tested on a sample of two hundred and eighty-five undergraduate students, were reported in Pazzaglia et al (2000). Reliability, measured by the split-half method (corrected by Spearman–Brown), was 0.75.

2.1.3 *Procedure.* Each participant was tested individually. Half of the participants completed the QSR before and the other half after the pointing task. When performing the QSR, participants read the instructions, and then answered the items presented. No time limit was given, but the entire procedure required, on average, 15 min.

Just before the directional-judgment tasks, the participants were told that they had to learn simple maps, and then perform several directional judgment tasks: ie by imagining being in a given position on the map, but facing another, they had to extend their arm pointing towards a third location. Each map was shown for 3 s. During the learning phase, the participant sat on a table. Then he/she would stand up, reach the centre of the protractor laid out on the floor and, facing towards zero, close his/her eyes and execute the experimenter's instructions by extending his/her arms towards the given point. Thus, it was assumed that the position in the centre of the circle was the position actually given to the pointer and that zero corresponded to the position of the landmark towards which the participant had to imagine he/she was facing. The participant then extended his/her arm towards the imagined position of the given landmark and the experimenter recorded the angle, following the grades marked along the circumference, and the time elapsed between instruction and arm extension (in seconds). Two trials were performed with each map, for a total of 12 trials of which 4 were aligned and 8 misaligned. Of the 8 misaligned trials, 4 were counteraligned (misaligned by 180°) and 4 were misaligned by amounts other than 180° (2 by 45°, 2 by 135°). The two trials given on the same map were always aligned differently. With reference to the map shown in figure 2, an example of an aligned trial would be: "Imagine being at point 2, facing point 1, and pointing towards point 3"; counter-aligned: "Imagine being at point 1, facing point 2, and pointing towards point 3"; misaligned by 45°: "Imagine being at point 2, facing point 3, and pointing towards point 1"; misaligned by 135°: "Imagine being at point 3, facing point 2, and pointing towards point 1".

2.2 *Results*

2.2.1 *Questionnaire on spatial representation.* Groups high and low on the MRT were compared on the questionnaire scores with respect to their preference for landmark-centred, route, and survey representations. As expected, the two groups differed in: (i) survey scores ($t_{50} = 3.36$, $p < 0.005$), with scores lower for the low MR ability group ($M = 4.60$, $\mathrm{SD} = 1.73$) than for the high MR ability group ($M = 6.32$, $\mathrm{SD} = 1.94$); (ii) route scores ($t_{49} = 2.36$, $p < 0.05$), with scores lower for the low MR ability group ($M = 6.27$, $\mathrm{SD} = 1.36$) than for the high MR ability group ($M = 7.23$, $\mathrm{SD} = 1.51$). No differences were found in landmark-centred scores ($t_{50} = 0.27$, $p = 0.79$; low MR ability group: $M = 7.70$, $\mathrm{SD} = 1.49$; high MR ability group: $M = 7.59$, $\mathrm{SD} = 1.40$).

2.2.2 *Assessing individual differences.* Following a procedure similar to that described by Rossano et al (1995), two criteria were used for distinguishing between participants showing an alignment effect and those who did not. The first criterion was that a participant was classified as showing an alignment effect if his/her percentage ratio (counteraligned error/aligned error $\times$ 100) was equal or greater than half of the overall percentage ratio between counteraligned and aligned error (average-counteraligned-error/average-aligned-error $\times$ 100). In the present study, the average counteraligned error, computed on fifty-two participants, was 67° and represented a 478% relative to the average aligned error (14°). Therefore, a participant needed to show at least a percentage ratio between counteraligned and aligned error equal to 239 to be classified as having shown an alignment effect. Second, a participant was classified as showing an alignment effect only if his/her counteraligned error was equal to or greater than 7°, which was half of the overall average aligned error.

Following these criteria, sixteen participants (31%) were classified in the no-effect subgroup, and thirty-six participants (69%) in the alignment effect subgroup. Percentages are similar to those reported by Rossano et al (1995; experiment 1), which were 29% and 71%, respectively.

Of the participants classified as belonging to the alignment effect subgroup (thirty-six participants), twenty-three were with low and thirteen with high MR ability. Of the sixteen participants classified in the no-effect subgroup, seven were with low and nine with high MR ability. The χ^2, calculated on frequencies of high and low MR ability individuals in the two subgroups, was not significant ($\chi^2_1 = 1.84$, $p = 0.17$).

2.2.3 *Pointing tasks.* The dependent measures in each pointing task were response times and absolute angular error, defined as the absolute difference between correct and selected angle. Two participants unable to perform all the pointing tasks were excluded from the analyses.

A 4×2 ANOVA for mixed design (alignment $\times$ group) was computed on response times. The only reliable effect was the main effect of alignment ($F_{3,138} = 12.71$, MSE $= 4.11$, $p < 0.001$). Multiple comparisons showed that times differed according to alignment conditions, with the fastest performance occurring in the aligned condition, which significantly differed from all others ($M = 1.95$, SE $= 0.16$). No differences were found between misaligned 45° ($M = 3.67$, SE $= 0.44$), misaligned 135° ($M = 3.98$, SE $= 0.38$) and counteraligned 180° ($M = 4.31$, SE $= 0.41$) conditions. A 4×2 ANOVA for mixed design (alignment $\times$ group) computed on angular error revealed a significant group effect ($F_{1,48} = 11.79$, MSE $= 1223$, $p < 0.005$), due to a better performance by the high MR ability group ($M = 37.05$, SE $= 3.73$) compared to the low MR ability group ($M = 54.15$, SE $= 3.30$), and a significant main effect of alignment ($F_{3,144} = 30.16$, MSE $= 883$, $p < 0.001$). Multiple comparisons showed that performance differed according to alignment, with the best performance in the aligned condition, which significantly differed from all other conditions. This was followed by the misaligned by 45°, which was better than both the 135° and 180° conditions. See table 1 for average angular error in the four conditions.

A significant interaction group $\times$ alignment was found ($F_{3,144} = 5.00$, MSE $= 883$, $p < 0.005$). As shown in table 1, the two groups were differently affected by conditions. Newman–Keuls a posteriori comparisons (critical difference $= 18$) showed that, in the low MR ability group, the four conditions differed from each other, except for the 45° and the 135° conditions. Whereas in the high MR ability group the aligned condition produced results better than the others, no difference was found between the 45°, 135°, and 180° conditions. Further comparisons between the two groups in the four conditions showed that they differed only in the counteraligned condition.

Table 1. Average angular error (in degrees) and standard error across orientation conditions in experiment 1.

Orientation conditions/°	High MR ability group		Low MR ability group		Overall	
	M	SE	*M*	SE	*M*	SE
0	9.66	3.82	16.47	3.39	13.07	2.55
45	41.39	4.14	48.95	3.67	45.17	2.76
135	54.80	5.30	63.32	4.70	59.06	3.54
180	42.37	10.78	87.87	9.56	65.13	7.20

2.3 *Discussion*

2.3.1 *Questionnaire on spatial representation.* The administration of the QSR allowed us to collect further information on the differences between the groups with high and low MR ability, and to stress the relation between MR and spatial representations. Route and survey scores for the low MR ability group were lower than those for the other participants, but no differences were found in landmark-centred scores. These results suggest that individuals with low MR ability have representations of the environment poor in spatial features, and more focused on the visual characteristics of landmarks. This confirms the results of Pazzaglia and De Beni (2001) and emphasises the relation between survey and route spatial representations and MR ability. The origin of this relation is to a great extent still unknown. An explanation is that constructing and maintaining route and survey representations share with MR a common ability to actively manipulate spatial configurations.

2.3.2 *Individual differences.* Analysis of individual differences showed results similar to those of Rossano et al (1995). The proportion of participants who did not show an alignment effect was approximately 30% both in the present study and in the study of Rossano et al (1995). This result confirms that, even if the alignment effect is robust and consistent, as demonstrated in the present and several other studies (Presson et al 1989; Presson and Hazelrigg 1984; Rossano and Warren 1989), it is not so widespread and that individual differences are important in this area of spatial cognition.

On the basis of our hypothesis that participants with high MR ability are less susceptible to the alignment effects, we expected a significantly higher percentage of participants with high MR ability in the no-effect subgroup and a smaller percentage in the alignment effect subgroup. Results are not definitive. In fact, in the no-effect group, 44% of participants were of low and 56% of high MR ability. Conversely, in the alignment effect subgroup, 64% were of low and 36% of high MR ability. Although data are in the direction of the hypothesis, the differences are not significant.

2.3.3 *Pointing tasks.* Overall, results on angular errors in the pointing tasks demonstrated better performance of the group with high MR ability. The relationship between MR ability and the alignment effect was also supported by the interaction between group and alignment: the low MR ability group was significantly affected by the variations in each condition (aligned, misaligned, counteraligned). For the high MR ability group the difference between aligned and non-aligned conditions was the only relevant one. No differences emerged in the high MR ability group between the two misaligned and the counteraligned conditions. On the basis of these and previous results we cannot conclude that the high MR ability individuals are free from the alignment effect, considering they performed better in the aligned than in the non-aligned conditions but, rather, the high MR ability individuals appear less sensitive to variations between misaligned and counteraligned conditions. Being positioned at 45°, 135°, or 180° from the learning perspective has no effect on the accuracy of performance of the high MR ability individuals, who can mentally adopt and maintain efficiently the new positions.

Given that the two groups differed in their MR ability, we could expect a different time performance in the pointing tasks. In fact, it was plausible to expect that, in the orientation phase at least, the high MR ability group would perform faster. Despite this, we did not find differences in relation to the groups, but only as a function of the alignment condition. Differences in performance time between the aligned and non-aligned conditions have emerged in several previous studies (Féry and Magnac 2000; Nori and Giusberti 2002; Roskos-Ewoldsen et al 1998). The lack of a significant effect of the main group factor may be due to the fact that we recorded global times between the moment instruction was given and pointing, with no distinctions between the first phase (orientation) and the second (pointing). With regard to this, Presson and Montello (1994) and Féry and Magnac (2000) found that only orientation times were sensitive to their experimental conditions, unlike the pointing latencies. A second interpretation is that the two groups were truly equal in performance times. The same result was obtained by Nori and Giusberti (2002), where no significant main effect for group on performance times for landmark-centred, survey, and route individuals was found. If so, the crucial point in performing non-aligned direction judgments tasks would not be speed in the orientation phase, but the ability to update position and efficiently maintain it in order to perform accurately a pointing task. This is supported by the result that the angular errors of the two groups differed in the counteraligned, but not the aligned condition. Thus, when required to assume and maintain a 180°-rotated perspective, people with low MR ability are particularly disadvantaged.

3 Experiment 2

Results of the first experiment partially support the role of MR in attenuating the alignment effect. Participants with higher MR ability were less sensitive to variations between 45°, 135°, and 180°. However, their increase in angular error from an aligned to a counteraligned perspective was similar to that of the low MR ability group. In this second experiment we studied individual differences on the alignment effect as a function of MR ability and map learning. The influence of map learning on pointing tasks was investigated with a complex and realistic map, which needed a long learning period. This map was studied in four learning phases, each followed by several directional judgment tasks. Our hypothesis was that the alignment effect would be reduced when the map was overlearned, because participants could construct a more abstract model, not related to the perspective of the represented environment. We further hypothesised that this phenomenon would be more evident in participants with high MR ability. In order to generalise the outcomes obtained with the MRT, a different mental rotation measure was used in this second experiment, the BCR-S by Reuchlin and Valin (1971).

3.1 *Method*

3.1.1 *Participants.* Eighteen undergraduate students (one male, seventeen females) split into two groups: a high MR ability group composed of twelve participants (one male, eleven females) and a low MR ability group composed of six participants (all females). The two groups were selected from a sample of one hundred and thirty-one undergraduate students on the basis of their performance on the BCR-S by Reuchlin and Valin (1971). The BCR-S consists of 40 items each composed of a target 3-D visual stimulus followed by four test stimuli. Participants have to choose among the test stimuli the one identical to the target, although presented from a different perspective. Forty participants performing equal to, or worse than, the 30° percentile (score = 15) were considered as belonging to the low ability range, thirty-nine participants performing equal to, or better than, the 70° percentile (score = 23) were reported as being of high ability. Eighteen of the selected participants volunteered to participate in the experiment.

3.1.2 *Materials.* A schematic two-dimensional map of a fictitious city (Sgaramella et al 1995), revised according to the guidelines for the plan map in Rossano et al (1995, experiment 2) was used. The original map was printed on an A4 sheet of paper. A reduced and simplified version is shown in figure 3. The map consists of 30 buildings (shops, banks, churches, etc) connected by a network of streets. Buildings are indicated by circles provided with specific labels (for example: flower-shop, bank, post-office). Streets are represented by two parallel lines with the road's name in between. The post-office, the newsagent, and the bank (respectively, posta, edicola, and banca in figure 3), located approximately in the middle of the map, were the places from which directional judgments were given.

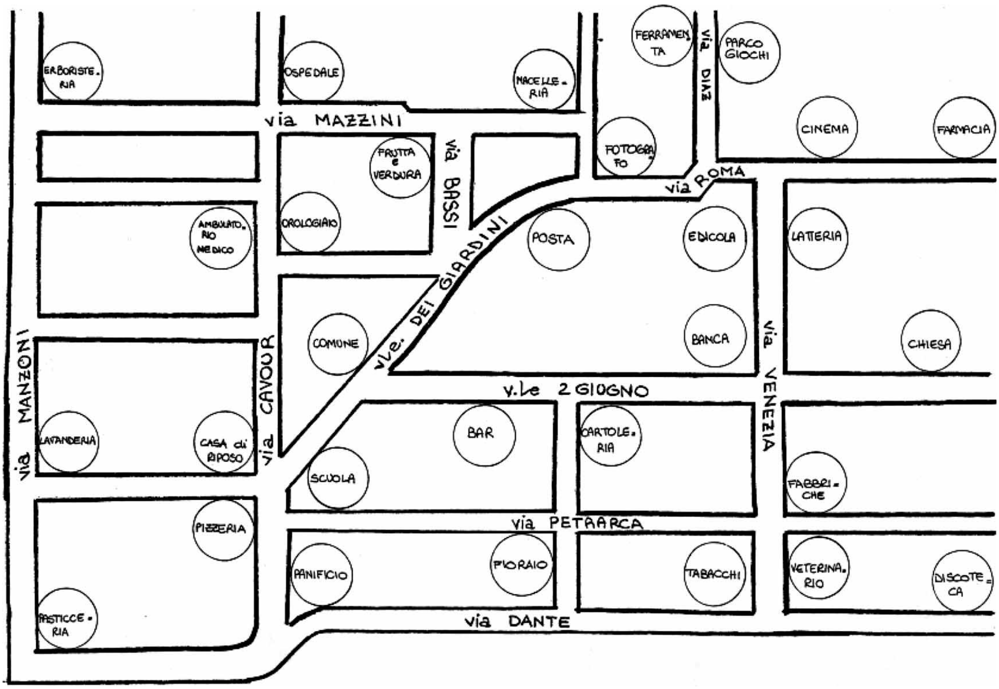

Figure 3. A reduced and simplified version of the map used in experiment 2.

3.1.3 *Procedure.* All participants were tested in a single group. The experimenter gave each participant a map and a test packet with sixteen sheets, each containing six circles. Circles had a dot in the centre and an arrow extending vertically from the dot to the top of the circle. Participants were told that the dot represented their location and the arrow the point they were facing. Participants were also told that they had to study the map on four occasions and, after each learning phase, perform several pointing tasks by imagining being in a given position on the map and facing another. They were told to respond to the pointing tasks by marking the perimeter of the circle with a straight line indicating the direction of the target landmark. After the first learning phase participants were required to turn the map over and take the corresponding sheet in the test packet containing 24 directional judgments, six for each condition. The experiment continued with the remaining learning phases, each followed by the corresponding test (24 directional judgments, six for each condition after each learning phase). Each learning phase lasted 5 min.

Three landmarks on the map (banca, posta, edicola) were used to give the exact position and orientation of the pointing tasks. In the aligned condition, participants had to imagine being in the banca, facing towards the edicola. In the counteraligned (180°)

condition they had to image being in the edicola, facing towards the banca. In the 90°-right misaligned condition they had to image being in the edicola facing the posta, and vice versa for 90°-left misaligned condition. Twenty-four landmarks were chosen from the map and assigned randomly to four six-landmark sets. The only constraint was that no more than three landmarks in each set could be from the same general map region. Each set was assigned to a different alignment condition across the four learning phases, so that all 24 test items occurred in each orientation condition. Orientation conditions were presented in four orders, one for each different learning phase.

3.2 *Results*

3.2.1 *Assessing individual differences.* The same criteria for classifying participants' performance as those used in experiment 1 were used in the present experiment. Because participants were tested four times, criteria were applied on the overall angular error derived by averaging the four testing phases. To be classified as having shown an alignment effect, a participant needed to have at least a 147% increase on the counteraligned error and his/her counteraligned error had to be equal to, or greater than, half of the overall average aligned error (16°).

In order to investigate eventual changes in the occurrence of an alignment effect through the four learning phases, we considered separately the first and the fourth. In the first learning phase, all participants showed an alignment effect. Unlike this, in the fourth learning phase, half (nine) of eighteen participants did not show an alignment effect. The no-effect group was composed entirely of high MR ability individuals. Table 2 shows frequencies of high and low MR ability individuals in the effect and no-effect groups. A χ^2 (Monte Carlo correction) statistical analysis showed a significant effect ($\chi^2_1 = 9.00$, $p < 0.005$).

Table 2. Frequencies of individuals with high and low MR ability in the effect and no-effect groups of experiment 2.

	Effect group	No-effect group	Total
High MR ability group	3	9	12
Low MR ability group	6	0	6

3.2.2 *Pointing tasks.* The dependent measure in each pointing task was absolute angular error, defined as the absolute difference between the correct and the pointed angle. A $4 \times 4 \times 2$ ANOVA of mixed design (learning $\times$ alignment $\times$ group) was computed on the angular error. The analysis showed a significant effect of group ($F_{1,16} = 7.96$, $\text{MSE} = 5163$, $p < 0.05$), due to the better performance of the high MR ability group ($M = 48.61$, $\text{SE} = 5.19$) than the low MR ability group ($M = 73.95$, $\text{SE} = 7.33$), and a significant main effect for alignment ($F_{3,48} = 46.13$, $\text{MSE} = 912$, $p < 0.001$). Multiple comparisons showed that the best performance was in the aligned condition, and the worst in the counteraligned, which differed from each other and from the two misaligned conditions. Misaligned 90°-right and 90°-left did not differ from each other. See table 3 (right column) for average angular error in the four alignment conditions.

Learning also resulted in a significant main effect ($F_{3,48} = 7.02$, $\text{MSE} = 1005$, $p < 0.005$). Multiple comparisons showed that the best performance was in the fourth learning phase. The fourth learning phase differed from the first three, which did not, however, differ from each other. See table 3 (line below) for the average angular error in the four learning phases.

The interaction between alignment and learning was also significant ($F_{9,144} = 4.22$, $\text{MSE} = 420$, $p < 0.001$). As shown in table 3, in the first learning phase all conditions

Table 3. Average angular error (in degrees) and standard error across learning (L) and orientation conditions in experiment 2.

Orientation conditions/°	L1		L2		L3		L4		Overall	
	M	SE	*M*	SE	*M*	SE	*M*	SE	*M*	SE
0	30.5	4.1	30.9	4.4	32.8	4.7	32.6	4.1	31.6	2.7
90-right	68.8	6.2	60.4	7.6	70.0	6.8	49.9	7.6	62.3	5.7
90-left	74.7	5.6	58.1	6.8	55.8	6.9	39.1	6.5	57.1	4.9
180	113.3	8.9	108.8	12.4	88.0	10.1	66.0	11.5	94.1	7.7
Overall	71.8	6.9	64.7	5.9	61.7	5.6	46.9	6.1		

differed from each other, unlike in the fourth learning phase where only aligned and counteraligned conditions were significantly different.

Finally, a significant group × alignment interaction was found ($F_{3,48} = 8.47$, MSE $= 912$, $p < 0.001$). As shown in table 4 the two groups were differently affected by conditions. A Tukey a posteriori comparison showed that in the low MR ability group the four conditions differed from each other, except for the 90°-left and 90°-right, whereas in the high MR ability group the only significant difference was between the aligned and counteraligned conditions. Comparisons between the two groups in the four conditions showed that they differed only in the counteraligned condition.

Table 4. Average angular error (in degrees) and standard error across orientation conditions in experiment 2.

Orientation conditions/°	High MR ability group		Low MR ability group	
	M	SE	*M*	SE
0	31.74	3.14	31.47	4.44
90-right	48.65	6.61	75.92	9.35
90-left	46.55	5.71	67.75	8.07
180	67.50	8.85	120.66	12.52

3.3 *Discussion*

3.3.1 *Assessing individual differences.* Results of the second experiment, on the one hand confirm the outcomes of experiment 1 and on the other hand extend them. Again, in accordance with previous research and results from experiment 1, a clear alignment effect emerged in the performance of the entire study population in both the aligned and non-aligned pointing tasks, but a percentage of participants (50% in the fourth learning phase) no longer showed an alignment effect. Interestingly, the no-effect group was entirely composed of high MR ability participants. Thus, an analysis of individual differences strongly supports the idea that high MR ability individuals are less sensitive to alignment effects. Compared to experiment 1, the relationship between MR and the occurrence of an alignment effect was neater, owing to the more complex map and to the fact that several learning phases had been added. It seems that practice helps the high MR ability group to adopt more effective strategies. Probably, as expected, knowledge of the map is also an important factor in determining the construction of a more perspective-free spatial representation. Further research may be useful to clarify to what extent these factors, ie practice in complex pointing tasks and map knowledge, concur in reducing the alignment effect in high MR ability individuals.

3.3.2 *Pointing tasks.* Angular errors of the high and low MR ability groups in the four alignment conditions confirm results of the assessment based on individual differences. In fact, the low MR ability group was affected by variations among alignment conditions, whereas the high MR ability group was sensitive only to differences between the aligned and counteraligned conditions. As in experiment 1, our high MR ability group is not equivalent to Rossano et al's (1995) no-effect group. The pattern of results is, in fact, different, with no differences between aligned and counteraligned conditions in Rossano et al's (1995) no-effect group, but with differences present between aligned and counteraligned conditions in our high MR ability group. Nevertheless, taken together, our results confirm that MR has a crucial role in reducing alignment effects, although it may not be the only determining variable.

4 General discussion

Although many investigators have reported robust alignment effects (Levine et al 1982; Rossano and Warren 1989), several experiments (Nori and Giusberti 2002; Rossano et al 1995) have demonstrated that a significant subgroup of individuals tends not to show an alignment effect at all. Studying the cognitive characteristics of these individuals, and pinpointing what sets them apart from those showing an alignment effect, can help to clarify which cognitive mechanisms are involved and which encoding strategies and methods of manipulation of spatial representations can be used most successfully.

In the present study, we examined if MR is involved in performing aligned and non-aligned pointing tasks and if individual differences in MR can explain differences in the occurrence of the alignment effect. In doing so, we compared groups of participants with high and low MR ability in several pointing tasks.

The results of our experiments indicate that MR is an important factor in the performance of pointing tasks and in reducing susceptibility to alignment effects. In both experiments, individuals with high MR ability performed pointing tasks better than those with low MR ability, particularly when they were required to assume a perspective counteraligned to that assumed during the learning phase. As a consequence, we can affirm that MR is involved in the capacity for directional judgment based on the construction, maintenance, and manipulation of spatial mental representations.

Individuals with high MR ability were also less susceptible to alignment effects. They performed equally well when tasks were misaligned by 45°, 135°, and 180°, in experiment 1; and when tasks were misaligned by 90° and 180°, in experiment 2. This pattern of results differed from that observed in low MR ability individuals, whose performance was influenced by each variation between aligned, misaligned, and counteraligned conditions.

When compared to the results of Rossano et al (1995) we cannot affirm that our high MR ability groups have exactly the same characteristics as their no-effect group. In fact, individuals in the high MR ability group performed worse in the counteraligned than in the aligned directional judgments, and as a consequence they were subject to an alignment effect. However, the assessment of individual differences by criteria similar to those adopted by Rossano et al (1995), showed that a larger proportion of individuals with high MR ability entered our no-effect group. Actually, in experiment 2 of the present study all the participants classified as not having an alignment effect were of high MR ability.

Another interesting result, especially with reference to those of Nori and Giusberti (2002), is that the highest scores in route and survey representations were obtained by individuals with high MR ability manifesting a preference for survey and route representations, but not for visual ones. This result suggests that MR, or at least spatial abilities, are related to spatial representation preferences. People with low spatial abilities prefer to adopt spatial representations focused on visual characteristics of salient landmarks; individuals with high spatial abilities can use visual features as well, but can also adopt more sophisticated spatial representations from route and survey perspectives.

Finally, results of experiment 2 stress the importance of learning factors interacting with spatial abilities in the construction of perspective-free spatial representations. After the first map-learning session all participants showed an alignment effect regardless of their level of MR ability. However, after the fourth session, nine out of twelve high MR ability participants no longer showed an alignment effect. With reference to several studies on mental models based on spatial descriptions (Bosco et al 1996; Pazzaglia et al 1994) or studies which compared navigation (in real and virtual environments) to map inspection (Richardson et al 1999), we can explain our results as being due to the ability of studying the material in more depth, adopting different perspectives and creating new orientation-dependent representations which can be easily and quickly transformed (eg Humphrey and Khan 1992). A second possibility is that participants with high spatial ability can learn through practice to use more efficient strategies in performing both aligned and counteraligned pointing tasks. Further research will be necessary to distinguish between knowledge of spatial configurations and familiarity with the tasks.

Collectively, these findings indicate that several factors contribute to a successful performance in aligned and non-aligned pointing tasks. Individual differences are influential in adopting a more or less perspective-dependent representation. People with high MR ability and with a preference for survey and route spatial representations were more likely to have perspective-independent representations. However, practice on the task and several map-learning phases were also seen to positively influence performance.

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Appendix 1. Questionnaire on Spatial Representation (Pazzaglia et al 2000)

1. Do you think you have a good sense of direction?
   1 (not at all), 2, 3, 4, 5 (very good)
2. Are you considered by your family or friends as having a good sense of direction?
   1 (not at all), 2, 3, 4, 5 (very much)
3. Think about the way you orient yourself in different environments around you. Would you describe yourself as a person:
   (a) who orients him/herself by remembering routes connecting one place to another
   1 (not at all), 2, 3, 4, 5 (very much)
   (b) who orients him/herself by looking for well-known landmarks
   1 (not at all), 2, 3, 4, 5 (very much)
   (c) who tries to create a mental map of the environment
   1 (not at all), 2, 3, 4, 5 (very much)
4. Think of an unfamiliar city. Write the name......
   Now try to classify your representation of the city:
   (a) survey representation, that is a map-like representation
   1 (not at all), 2, 3, 4, 5 (very much)
   (b) route representation, based on memorizing routes
   1 (not at all), 2, 3, 4, 5 (very much)
   (c) landmark-centred representation, based on memorizing single salient landmarks (such as monuments, buildings, crossroads, etc).
   1 (not at all), 2, 3, 4, 5 (very much)
5. When you are in a natural, open environment (mountains, seaside, country) do you naturally individuate cardinal points, that is where North, South, East, and West are?
   1 (not at all), 2, 3, 4, 5 (very much)
6. When you are in your city do you naturally individuate cardinal points, that is do you find easily where North, South, East, and West are?
   1 (not at all), 2, 3, 4, 5 (very much)
7. Someone is describing for you the route to reach an unfamiliar place. Do you prefer:
   (a) to make an image of the route
   1 (not at all), 2, 3, 4, 5 (very much)
   (b) to remember the description verbally
   1 (not at all), 2, 3, 4, 5 (very much)
8. In a complex building (store, museum) do you think spontaneously and easily about your direction in relation to the general structure of the building and the external environment?
   1 (not at all), 2, 3, 4, 5 (very much)
9. When you are inside a building can you easily visualize what there is outside the building in the direction you are looking towards?
   1 (not at all), 2, 3, 4, 5 (very much)
10. When you are in an open space and you are required to indicate a compass direction (north-south-east-west), do you
    (a) point immediately
    (b) need to think before pointing
    (c) have difficulty
11. You are in a complex building (many floors, stairs, corridors) and you have to indicate where the entrance is, do you
    (a) point immediately
    (b) need to think before pointing
    (c) have difficulty

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