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Alignment effect: primary – secondary learning and cognitive styles

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Abstract. The degree to which the way of learning spatial information (primary/secondary learning) and spatial cognitive style (landmark/route/survey) affect orientation specificity (alignment effect) is studied. We think that the most important factor explaining the absence of the alignment effect is the spatial cognitive style. We hypothesise that while landmark participants show an alignment effect after both primary and secondary learning, route participants show this effect only after secondary learning, and survey participants do not show it at all. Participants performed three tasks in order to distinguish their cognitive style; they were then randomly assigned to primary or secondary learning and submitted to directional judgment tasks to verify whether the alignment effect was present. The results confirm our hypothesis.

1 Introduction

For many of our daily activities, knowledge of the spatial organisation of the environment is necessary. An important property of spatial knowledge is that it can be retrieved and used efficiently from familiar perspectives, but when we are required to access spatial knowledge from an unfamiliar point of view, we may have difficulty in creating and maintaining a coherent representation of the environment (Levine et al 1982; Valiquette et al 2003). For example, when we walk along a usual route, we pay little attention to landmarks and routes because it is quite easy to stay oriented. If we approach a familiar route from an unfamiliar direction, mental effort is required to find our bearings and to recognise where we are. In literature, this effect is known as orientation specificity, which is when memorial representations are coded (and hence accessed) in a single preferred direction.

Over the past 20 years, the orientation specificity of human spatial memory has been an interesting topic of scientific inquiry. The orientation-specific representation is inferred from the *alignment effect*—an easier judgment of relative location when the person's orientation with respect to the spatial array at test (either in reality or in the imagination) is aligned with his/her orientation at learning than when it is contra-aligned (rotated by 180°) such that this relationship is reversed.

Several studies on spatial memory, in fact, have shown that people are more accurate and faster in direction judging both when the 'up' direction on the map is the same as the 'forward' direction in the environment (real situation) and when their imagined map perspective is the same as their learned perspective (imaginary situation). This effect is known as the alignment effect (eg Huttenlocher and Presson 1973; Levine 1982; Levine et al 1982; Easton and Sholl 1995; Roskos-Ewoldsen et al 1998; Richardson et al 1999—map and virtual-walk conditions; Shelton and McNamara 2001a, 2001b, 2001c; Mou and McNamara 2002; Valiquette et al 2003).

However, Rossano et al (1995) found that the alignment effect cannot be generalised: a subgroup of their participants did not show any alignment effect. Moreover, Nori and Giusberti (2002, 2003) have shown that the alignment effect depends on the different ways in which people represent spatial information: landmark, route, and survey.

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This hypothesis was based on Pazzaglia et al's (2000) model which has shown that these three types of mental representation correspond to three different spatial cognitive styles. Landmark people have a spatial representation that is rather poor in spatial components because it is only based on landmarks that are unique patterns of perceptual events. These people are able to move successfully in the environment even if they do not represent the route between two landmarks (Denis et al 1999). These people have a clear idea about the landmarks, but they do not have a clear idea about the relationship between them. This kind of spatial representation does not give any spatial information, such as the specific position of the landmark. Landmarks are used as course-maintaining devices, usually proximate, in order to maintain the navigational direction. This kind of representation seems to require a special kind of figurative memory. Route people have a spatial representation that relies on knowledge of landmarks and routes generally used to connect those landmarks. Whereas landmark representation is predominantly visual, route representation is considered to be sensorimotor (Siegel and White 1975). A person memorises routes in the form of a mental list of distances and directions that must be followed according to a precise sequence of motor actions, that is where to turn right or left at a specific landmark along the path. In fact, these people refer to landmarks and egocentric coordinates that are body references (head/feet, front/back, right/left axes). This type of representation does not have plasticity; that is, it is not prone to reorganisation.

Finally, survey people represent spatial information relying on global reference points such as the cardinal directions or the position of the sun in the sky when moving in the environment—that is, allocentric coordinates—and they are also able to use both egocentric coordinates and landmarks when they are useful to help them move successfully. This representation is characterised by a high level of plasticity and it is the necessary condition for inventing new routes. In general, survey representation could be considered a sophisticated device that gives its owner an advantage in wayfinding and organising experience. This model is cumulative because landmark representation is characterised by the properties of only landmark representation; route representation is characterised by the properties of both landmark and route representation; and survey representation is characterised by the properties not only of landmark and route but also of survey representation.

According to Nori and Giusberti's (2002, 2003) hypothesis, survey participants do not show any alignment effect, unlike landmark and route participants. The authors explain this result by the ability of survey participants to represent spatial information in allocentric coordinates.

These studies (Rossano et al 1995; Nori and Giusberti 2002, 2003) stressed individual differences to highlight the fact that the alignment effect cannot be generalised for everyone.

Other studies have brought to light the fact that the alignment effect can be reduced by forcing participants to acquire spatial information from different points of view, that is from multiple experiences with the environment (eg Evans and Pezdek 1980; Presson and Hazelrigg 1984; Presson et al 1989; Féry and Magnac 2000; Sholl and Bartels 2002). For instance, crossing a town frequently and freely along different paths makes it easier to use the spatial information in a variety of orientations. This contributes to reducing the alignment effect. More decisively, Presson and Hazelrigg (1984) examined the condition under which spatial information is represented in a flexible manner. In this work, people studied simple four-point paths, similar to those represented in figure 1, by viewing a map (map condition, secondary learning), by walking along them while blindfolded (walk condition, primary learning), or by viewing the path from a single vantage point (viewing path condition, primary learning).

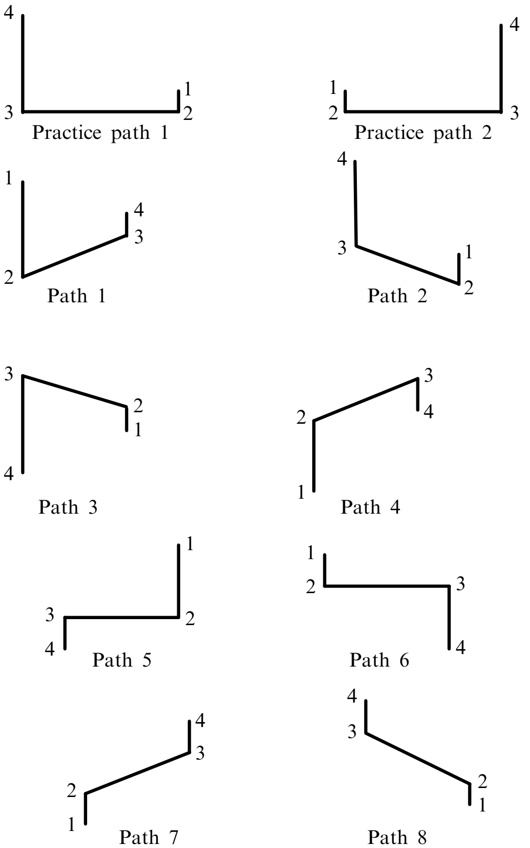

Figure 1. The rectilinear map/path used to test the alignment effect constructed according to the guidelines in Levine et al (1982).

After learning the path, participants were positioned (while blindfolded) at a particular location on the path. They were told their location and the direction they were facing. Then, the participants were asked to point to another location on the path. Results showed that, when the participants learned the paths indirectly, using a map, directional judgment tasks were easier if the learned perspective was the same as the imagined perspective and more difficult if the judgment was not aligned with the learned map orientation (alignment effect). However, when participants learned the paths more directly, by primary spatial learning (ie viewing path condition and walk condition), there was no alignment effect. The authors explained the absence of the alignment effect by the fact that people have direct access to spatial knowledge without considering the egocentric reference system. The information involved is specified in terms of an allocentric reference system. Presson et al (1987) have further shown that, when participants had experienced multiple orientations while learning the path, later directional judgments were equally accurate regardless of whether the judgments were aligned or contra-aligned with the orientation of the path as originally learned. In contrast, when paths were learned in a single orientation achieved through walking without turning, subsequent judgments on contra-aligned trials were both less accurate and slower than judgments on aligned trials. Sholl and Nolin (1997) found an absence of alignment effect when participants learned the four-point paths from a low viewing angle (eg while seated) and when they were tested when their physical location and facing direction at the time they made their pointing judgment matched those specified in the judgment of relative direction. Unfortunately, these same learning and test conditions produced an alignment effect in experiments conducted by Mou and McNamara (2001), although their participants learned more complex layouts (seven objects distributed on the floor of a large room as opposed to four-point paths). Richardson et al (1999) had participants learn the interior hallways of a large building by walking through the building (primary learning), by navigating a desktop virtual environment, or by learning a map (secondary learning). Alignment effect was revealed both in the virtual-walk and map condition but not in the real-walk condition. Moreover, Chan et al (2003) had participants learn the structure of a complex building by viewing a map (secondary learning), by navigating through that building (primary learning), or by navigating through realistic interactive virtual simulation of that building by pedalling a stationary bicycle while receiving visual feedback (virtual condition). Alignment effect was revealed in the map condition but not in the two navigation conditions (real and virtual).

However, other evidence indicates that learning a large-scale environment from several orientations is not sufficient to produce an orientation-free representation. For example, McNamara et al (2003) had participants learn the location of eight objects in an unfamiliar city park by walking through the park on one of two prescribed paths that encircled a large rectangular building. In the aligned condition, the path had the same orientation as the building, whereas in the misaligned condition the path was rotated by 45°. After learning the path, participants pointed to target objects from imagined vantage points, using memories. Results showed that pointing accuracy was higher in the aligned than in the misaligned condition.

Moreover, other studies have shown that there is an absence of the alignment effect when participants have to learn a large display. In particular, Presson et al (1989) showed that small paths were coded in an orientation-specific way (alignment effect), whereas very large displays were coded in a more orientation-free manner, that is without an alignment effect. Contradicting this, Roskos-Ewoldsen et al (1998) showed that the alignment effect was present for both small and large layouts. Waller et al (2002, experiments 1 and 2) confirmed this result. However, the data on layout size are contradictory and it is not clear whether this factor can effectively eliminate the alignment effect.

McNamara (2003) underlined that an important feature common to all the studies in which orientation independence has been demonstrated, is that only two orientations conditions were compared: aligned (imagined perspective is the same as the learned one) and contra-aligned (imagined perspective is rotated by 180°). According to McNamara (2003), this fact could be important because performance in judgments of relative direction for contra-aligned condition is often much better than performance from other novel perspectives (eg Mou and McNamara 2002). The cause for this effect is not clear but the author postulated that participants sometimes represent the spatial structure of the layout in the contra-aligned direction. Another possible interpretation is that, under certain conditions, participants are able to capitalise on self-similarity under rotation of 180° (eg Vetter et al 1994).

However, some researchers do not corroborate this interpretation (Evans and Pezdek 1980; Nori and Giusberti 2003). In Evans and Pezdek's (1980) study, participants were shown sets of three building names and had to decide whether the buildings were arranged in the correct spatial configuration. Participants had to memorise the location of the building either naturally by navigation or by studying a map. Students who learned the map recognised the familiar upright views of the stimuli faster, and the difficulty in recognising unfamiliar, rotated stimuli was a linear function of the angular rotation. However, participants who had learned the layout naturally by navigation experienced no such relation.

Nori and Giusberti (2003) had participants learn a simple four-point path and were asked to perform three different directional judgment tasks: aligned (the imagined perspective was the same as the learned one), misaligned (the imagined perspective was rotated by 70°, 90°, or 110° from the learned one), and contra-aligned (the imagined perspective was rotated by 180° from the learned one). In this case, the aligned condition was easier and faster than misaligned and contra-aligned conditions but there was no significant difference between misaligned and contra-aligned directional judgments. This result supports the idea that the difficulty experienced in directional judgments depends on having to assume a different overall perspective from the learned one.

As shown above, there is little agreement in the literature on which factor is the most important in eliminating or attenuating the alignment effect. An important feature of the experiments in which orientation-independent performance has been observed is that people learn a path by walking; that is, when people have locomotor experience of the environment, particularly when the environment to be acquired is simple and similar to that represented in figure 1 (eg Presson and Hazelrigg 1984; Sholl and Nolin 1997) besides the individual differences, it is the spatial cognitive style used by people to acquire and represent spatial information that is important (eg Rossano et al 1995; Nori and Giusberti 2002, 2003).

We attempt to demonstrate here that the main factor explaining the absence or the attenuation of the alignment effect is the spatial cognitive style, and not the way of learning spatial information induced by the experimenter. More specifically, we hypothesised that, when a person uses a survey cognitive style, the alignment effect should not be evident, ie the accuracy and response time should not be affected. This applies to both primary (walk condition) and secondary (map condition) learning. We hypothesised this because survey cognitive style people are able to use both allocentric and egocentric coordinates and landmarks in solving spatial tasks. In primary learning participants acquire spatial information using egocentric coordinates and probably base it on a route-like representation, whereas in secondary learning they acquire spatial information on the basis of allocentric coordinates. They are then probably able to represent and use allocentric coordinates to solve spatial tasks. For these people, there is a coincidence between encoding and retrieval of spatial information both in primary and in secondary learning. This correspondence would lead to an attenuation or absence of the alignment effect because it is the most useful and economic strategy in terms of cognitive sources (Tulving and Thompson 1973) in solving tasks. We came to this conclusion because we think that these participants are able to change the orientation of the map image, and therefore they treat the contra-aligned directional judgment task as an alignment directional judgment task every time the correspondence between encoding and retrieval of spatial information is present. We also hypothesised that participants who use the route cognitive style would show an alignment effect in secondary learning but not in primary learning. This would imply, as for survey style users, that where there is a correspondence between the encoding and the preferred way of representing spatial information, the alignment effect should not appear or be attenuated. We think that these participants, like survey style users, are able to change the orientation of the map image, and, therefore, they treat the contra-aligned directional judgment task as an alignment one when they can acquire spatial information in their preferred way, that is walking along the route between two landmarks. For these participants, the correspondence between encoding and retrieval of spatial information is present only in the primary learning. Further, we hypothesised that landmark participants would show an alignment effect both in primary and in secondary learning because they have a representation which is rather poor in spatial components being based only on landmarks. As mentioned above, they do not have a clear idea where the landmarks are located in relation to the overall spatial array: they have a spatial representation based merely on landmark figurative characteristics and not on their spatial relations. Since these people are not able to use egocentric and allocentric coordinates, there are no conditions where the correspondence between encoding and retrieval of spatial information can appear. For this reason, we think that they are not able to treat a contra-aligned directional judgment task as an alignment directional judgment task, so the alignment effect is bound to appear both in primary and in secondary learning.

2 Method

2.1 *Participants*

Two hundred and two students from the Department of Psychology of the University of Bologna were submitted to the selection phase (for more information see sections 2.2 and 2.3) but only one hundred and thirteen were selected to take part in the experimental phase on the basis of their answers to the selection-phase tasks. This group was made up of thirty-eight landmark participants (nine males and twenty-nine females), forty route participants (sixteen males and twenty-four females), and thirty-five survey participants (sixteen males and nineteen females). They were aged between 19 and 31 years, mean age = 23.17 years, eighteen of whom were lefthanded.

The size of the initial group of participants (two hundred and two) was due to the difficulty in finding landmark and survey participants. We used the data from the first forty people who met the route criteria (see below for criteria). However, we kept testing individuals until we found about forty people who met the landmark and survey criteria. As a result, we did not include in the analysis data from eighty-nine route subjects (forty-one males and forty-eight females).

Since each group (landmark, route, and survey) was homogeneous because university students made it up, we thought that possible differences would concern only spatial ability and would not be referable to general intelligence differences. All participants volunteered to take part in the experiment.

2.2 *Materials*

In the selection phase, in order to distinguish the participants' cognitive style, we used the same criteria as those used by Nori and Giusberti (2003). The criteria consisted of three cognitive tasks which assessed different aspects of spatial knowledge.

2.2.1 *Landmark task.* To test the ability of participants to use patterns which were perceptually salient, the participants had to recognise a photo (target) they had previously studied for 3 s from a set of four subsequently introduced (one target, three fillers) (Bosco et al 2004). The photos represented similar buildings by the presence or absence of specific objects such as a vase of flowers, a car, a sign, etc. Every participant had to solve seven different trials of this task. Participants who gave at least 80% of correct answers were classified as having landmark cognitive style because, in order to solve the task, they could mentally represent perceptually salient patterns without referring to any kind of spatial information about them. Furthermore, in order to be labelled as 'landmark', the participants had to have 50% (chance level) or fewer correct answers both in route and in survey tasks (Nori and Giusberti 2003).

2.2.2 *Route tasks.* To test the ability of the participants to use egocentric coordinates, they had to learn a circular path in the Department of Psychology, which is a building with three floors and a basement. As in Nori and Giusberti (2003), the path involved the basement and the first floor and measured approximately 250 m. Along the route there were 9 landmarks and 17 turning points.

In the acquisition phase, the experimenter accompanied the participants at the starting point of the route and said: "This is where our tour begins. We will walk along a circular path 3 times. It is necessary that you pay attention to the objects along the path: the stairs, a desk, a door, some chairs, etc, and at the turning points. Your task will be to describe to me the path from the starting point to the ending point (which is the same as the starting point because the path is circular)". Then the experimenter led the participants along the path.

In the testing phase, the experimenter told the participant to imagine himself/herself at the starting point of the path. Then the experimenter said: "Your task is to describe the path from the starting point to the ending point as accurately as possible. You have to do this as if you were describing it to a person who does not know the path and who has asked you for information on how to reach the ending point from the starting position".

Then the participant started to describe the path. The experimenter wrote down the participant's description of the path on a response sheet of paper.

As the criteria required, each participant was given a point for every landmark and right/left turn that he/she remembered in the correct sequence. The participants who gave at least 80% of the correct directional information in this task and 80% of the correct answers in the landmark test used a route cognitive style because they refer both to landmarks and to egocentric coordinates. In order to be labelled as 'route', the participants had to give 50% (chance level) or fewer correct answers in the survey task (Nori and Giusberti 2003).

2.2.3 *Survey task.* To test the ability of participants to use allocentric coordinates, they had to judge the length of a series of segments (Massironi 1990). The experimenter showed on a sheet of paper (21 cm × 29.7 cm) a series of segments that the participant had to straighten and add mentally to judge the total length. Participants chose from four lines which one would be the correct length of the segments, if the segments had been straightened out. Then the participant had to mark the right answer among the four response lines presented on the same sheet of paper. Every subject had to participate in seven different trials of this task.

In this case, the participants had to rely exclusively on an abstract, internal representation characterised by a bird's-eye viewpoint, an object-centred reference system, ie a survey representation. For these reasons, the participants who gave at least 80% of correct answers on landmark, route, and also in this task, used a survey cognitive style because they refer both to landmarks, and to egocentric and allocentric coordinates (Nori and Giusberti 2003).

The three cognitive style tasks were randomised and all participants were submitted to them.

These tasks (landmark and survey tasks) constitute part of a spatial cognitive-style test (SCST) used to assess the cognitive style of a person navigating through the environment (Nori and Giusberti 2006). Nori and Giusberti (2006) submitted one hundred and seventy-nine participants to nine spatial tasks that were linked with the three forms of spatial representations described above (landmark, route, and survey). Results showed that the nine spatial tasks could be used to distinguish different spatial abilities. In fact, some people solved correctly only tasks that assessed the landmark style, some the route style, and some the survey style. In this work, the problems about convergent and divergent validation of the nine tasks had been treated. For example, findings from cluster analysis identified three clusters for the nine spatial tasks. From the characteristics of each cluster, we have argued that the first one included landmark tasks because to solve them people needed to mentally represent perceptually salient patterns without referring to any kind of spatial information. The second cluster included route tasks because they demonstrated a linear spatial ability organisation and right-and-left discrimination ability. Finally, the third cluster implied survey tasks because here one had to rely only on an abstract, internal representation, ie a survey representation.

To sum up, the series of analyses which we carried out revealed that the landmark task, used in this work, highly correlates with other landmark tasks but not with route and survey tasks; the same applies to route and survey tasks.

The participants' classification can be achieved with different spatial cognitive tasks but they have to be linked to the spatial characteristics of the landmark, route, and survey representation, as described above.

Ten paths were adopted from those used by Levine et al (1982) to test the alignment effect. Two of the paths were used only for practise. Each path was constructed with four points and three segments of varying lengths. The two turns consisted of angles that were either 110° and 70°, or 90° and 90° (see figure 1).

For the *map condition* (secondary learning), each path was printed on a sheet of paper (21 cm × 29.7 cm) and the length of the three segments of each path varied from 3.5 cm to 17 cm (Nori and Giusberti 2003).

For the *walk condition* (primary learning), the paths were the same as in the map condition but the length of the three segments of each path varied from 70 cm to 340 cm and they were made from heavy black cardboard (Presson and Hazelrigg 1984). In this condition, the paths were produced on a scale of 20 : 1.

We assigned a number from 1 to 4 to each corner of the path, starting at one corner and proceeding sequentially through the path (Presson and Hazelrigg 1984). The eight paths used for the experiment were randomised and then the same order was used for all participants (Roskos-Ewoldsen et al 1998; Nori and Giusberti 2003): two judgments of direction were made by participants for each path, one aligned and one contra-aligned, for a total of sixteen judgment direction tasks (eight aligned and eight contra-aligned). The order of these judgments was determined randomly for each path with the restriction that half the layouts had aligned judgments before contra-aligned and the other half had contra-aligned before aligned. The same order was used for all participants.

The correct response for aligned and contra-aligned judgments could be either in front of or behind the participants. Correct responses ranged from 45° to 305°. Participants used a cardboard dial with a diameter of 30 cm, similar to the one used by Roskos-Ewoldsen et al (1998), to give their directional judgments. Attached to the centre of the circular dial was a pointer that could be rotated 360°. Every 5° was marked (0° to 355°, clockwise) so that the experimenter could record the participants' responses. There were marks on the outer edge of the dial at 0°, 90°, 180°, and 270° to help the subjects to keep the direction in mind. The notch at 0° was larger than the others in order to enable subjects to keep 0° in the forward position.

A hand-held stopwatch was used to record response time.

2.3 *Procedure*

Each participant was tested individually. For the selection phase of the experiment, the participants had to solve the three cognitive tasks in order to distinguish the way they acquired and represented spatial information. On the basis of the participants' answers, following the criteria of Nori and Giusberti (2003), we allotted the participants to three groups: thirty-eight landmark, forty route, and thirty-five survey. Half of the participants in each cognitive style group were randomly assigned to the map (secondary learning) or to the walk (primary learning) condition. In the survey group, we had eighteen participants allotted to the walk condition and seventeen to the map condition.

After that, for the experimental phase, we told the participants that they would learn a series of four-point paths and they would be asked to make two directional judgment tasks. Participants were given detailed instructions regarding the circular cardboard dial. Participants were also told that they would be blindfolded during the procedure. Then, each participant learned eight paths in one of two conditions: map or walk.

In the *map condition* (secondary learning), participants viewed the paths for 30 s to learn the positions of the numbers. At the beginning of each trial, participants wore a blindfold and then the experimenter put the map on the table. At that moment, the participant removed the blindfold, viewed the path for 30 s, and, after learning the path, put the blindfold on again. During this time, the experimenter removed the path and put the circular cardboard dial on the table in order to let the participant carry out the directional judgment task.

In the *walk condition* (primary learning), blindfolded participants were seated in a wheelchair located at the end of the room. They were then wheeled to the path that started from the centre of the room. The experimenter then asked the participant to stand up and he/she was led to the beginning of the path, was told he/she was at location 1, and was led by the experimenter, who announced each location as it was encountered. At the end of the path, the subject was seated in the wheelchair and wheeled in a random and meandering route back to location 1 for his/her next walk along the path, until the path had been followed three times (Presson and Hazelrigg 1984). Each walk took approximately 30 s. After the learning phase, the participants were pushed in the wheelchair again and placed in front of the cardboard dial for the first judgment of direction.

At this point the procedures for the map and walk conditions became the same. Participants carried out two directional judgment tasks on each path: they were told to imagine themselves at a specific point on the path, to look at another point, and to point to a target location on the path using the circular dial. One of the directional judgment tasks was aligned (where the imagined perspective was the same as the learned one) and the other one was contra-aligned (where the imagined perspective was rotated by 180° from the learned one) in order to identify the presence or absence of the alignment effect. The experimenter started the hand-held stopwatch immediately after the target location was announced and stopped the stopwatch when the participants removed their hands from the dial. After completing one trial the procedure was repeated for the next path. The experimenter recorded the response time in seconds and the angular direction in degrees (read from the dial). This gave us as dependent variables the response time and absolute angular errors, calculated as the difference in degrees between the exact position and the position marked by the participants.

3 Results

In order to analyse the correct choice in the three spatial cognitive styles used in the selection phase (see sections 2.1 and 2.2), and to distinguish the spatial cognitive style used by each participant, we performed a correlation among the tasks across the original sample of two hundred and two participants on the number of correct responses. Before performing the correlation, we had standardised the score tasks (ie the z points). As expected from Nori and Giusberti (2006), the correlations between the three tasks were not reliable: landmark and route $= 0.09$; landmark and survey $= 0.02$; route and survey $= -0.12$.

A four-way analysis of variance with mixed designs was carried out with three levels of the between-variable 'cognitive-style participants' (landmark/route/survey), 2 levels of the between-variable 'primary/secondary learning' (walk/map condition), 2 levels of 'directional judgment tasks' (aligned/contra-aligned), and the 8 levels of path repeated factor. We analysed both absolute angular errors and the response time.

3.1 *Absolute angular errors*

The main effect of 'directional judgment tasks' (aligned/contra-aligned) was statistically significant ($F_{1,107} = 154.67$, $p < 0.000$). The means for the absolute angular errors (ϕ) were: aligned, $\phi = 38.87°$, SD $= 53.95°$; contra-aligned, $\phi = 94.70°$, SD $= 86.55°$.

The main effect of 'cognitive style participants' (landmark/route/survey) was statistically significant ($F_{2,107} = 47.28$, $p < 0.000$). Newman – Keuls a posteriori comparisons showed that landmark participants made mistakes of greater magnitude than route ($p < 0.001$) and survey ($p < 0.01$) participants. We also found that route participants made mistakes of greater magnitude than survey participants ($p < 0.01$), as shown in figure 2. The standard deviations for the three groups were: landmark, SD $= 84.44°$; route, SD $= 75.93°$; survey, SD $= 56.76°$.

The main effect of path was also statistically significant ($F_{7,749} = 3.86$, $p < 0.001$). Newman–Keuls a posteriori comparisons showed that path number 5 was the most difficult ($p < 0.05$), as shown in figure 3.

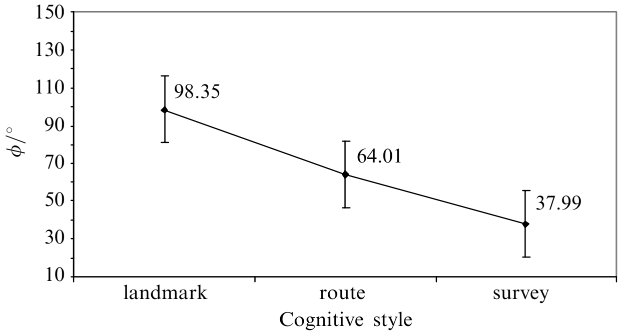

Figure 2. Mean absolute angular errors, ϕ, as a function of the three cognitive styles. Error bars are intervals corresponding to SEM as estimated from the ANOVA

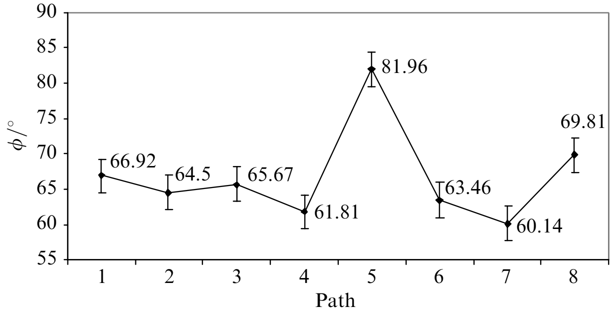

Figure 3. Mean absolute angular errors, ϕ, as a function of the eight paths. Error bars are intervals corresponding to SEM as estimated from the ANOVA.

We also found that the 'cognitive style participants' × 'directional judgment tasks' (landmark/route/survey × aligned/contra-aligned) showed a significant interaction ($F_{2,107} = 30.26$, $p < 0.0001$). Newman–Keuls a posteriori comparisons showed that aligned directional judgment tasks were easier than contra-aligned directional judgment tasks for both landmark (alignment versus contra-alignment, $p < 0.0001$) and route (alignment versus contra-alignment, $p < 0.001$) participants, but there was no such difference within survey participants (alignment versus contra-alignment, $p > 0.05$), as shown in figure 4, or if one exists, then its size was too small to be confirmed in the current study.

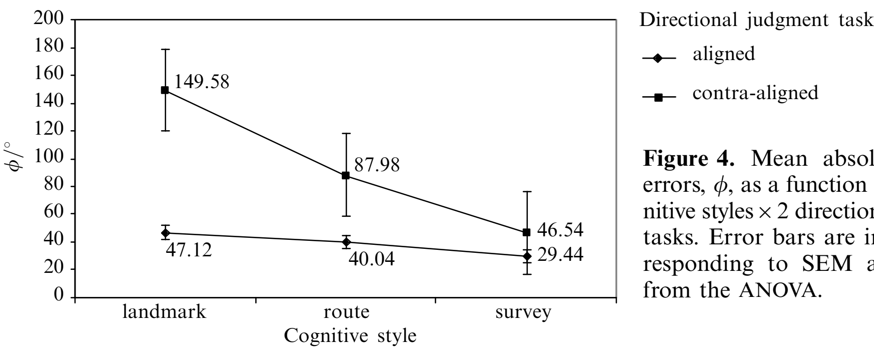

Figure 4. Mean absolute angular errors, ϕ, as a function of the 3 cognitive styles × 2 directional judgment tasks. Error bars are intervals corresponding to SEM as estimated from the ANOVA.

The interaction 'primary/secondary learning' × 'paths' (walk/map condition × path) was also statistically significant ($F_{7,749} = 5.75$, $p < 0.0001$). Newman – Keuls a posterori comparisons showed that path number 5 in the walk (primary learning) condition ($\phi = 98.72°$) was more difficult than the same path in the map (secondary learning) condition ($\phi = 65.20°$), ($p < 0.001$).

Moreover, we found the 'primary/secondary learning' × 'directional judgment tasks' (walk/map condition × aligned/contra-aligned) showed statistically significant interaction ($F_{1,107} = 35.66$, $p < 0.0001$). Newman – Keuls a posteriori comparisons showed that the aligned directional judgment tasks in the map (secondary learning) condition ($\phi = 26.84°$) were easier than in the walk (primary learning) condition ($\phi = 50.89°$) ($p < 0.001$). On the contrary, the contra-aligned directional judgment tasks were easier in the walk (primary learning) condition ($\phi = 79.91°$) than in the map (secondary learning) condition ($\phi = 109.49°$) ($p < 0.001$). Moreover, both after primary and after secondary learning the aligned directional judgment tasks were easier than the contra-aligned directional judgment tasks.

The most interesting result was that the 'cognitive style participants' × 'primary/secondary learning' × 'directional judgment tasks' (landmark/route/survey × walk/map condition × aligned/contra-aligned) showed significant interaction ($F_{2,107} = 7.85$, $p < 0.001$). Newman – Keuls a posteriori comparisons showed that for the landmark participants the aligned directional judgment tasks were easier than the contra-aligned directional judgment tasks both in walk (aligned, $\phi = 67.74°$ versus contra-aligned, $\phi = 124.75°$) ($p < 0.001$) and map (aligned, $\phi = 26.50°$ versus contra-aligned, $\phi = 174.40°$) ($p < 0.001$) conditions. For route participants the aligned directional judgment tasks were easier than the contra-aligned directional judgment tasks in the map (aligned, $\phi = 29.59°$ versus contra-aligned, $\phi = 110.28°$) ($p < 0.001$) but not in the walk (aligned, $\phi = 50.50°$ versus contra-aligned, $\phi = 65.68°$) condition. There was no such difference within 'survey' participants, both in walk (aligned, $\phi = 34.44°$ versus contra-aligned, $\phi = 49.30°$) and map (aligned, $\phi = 24.44°$ versus contra-aligned, $\phi = 43.78°$) condition, as can be seen in figure 5 or, if one exists, then its size was too small to be confirmed in the current study.

There were no other reliable main effects or interactions in this analysis.

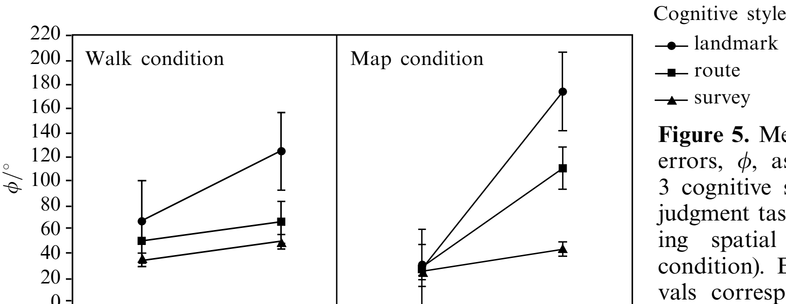

Figure 5. Mean absolute angular errors, ϕ, as a function of the 3 cognitive styles × 2 directional judgment tasks × 2 ways of learning spatial layout (walk/map condition). Error bars are intervals corresponding to SEM as estimated from the ANOVA.

3.2 *Response time*

The main effect of directional judgment tasks (aligned/contra-aligned) was statistically significant ($F_{1,107} = 19.28$, $p < 0.0001$). The alignment judgments were faster than the contra-aligned judgments. The means for the response time (τ) of the two judgments were: aligned, $\tau = 27.27$ s, SD = 33.41 s; contra-aligned, $\tau = 34.00$ s, SD = 47.87 s.

The main effect of 'cognitive style participants' (landmark/route/survey) was statistically significant ($F_{2,107} = 24.21$, $p < 0.0001$). Newman – Keuls a posteriori comparisons showed that survey participants (51.72 s) took longer than both landmark (23.67 s) and route (17.25 s) participants ($p < 0.001$). The standard deviations for the three groups were: landmark, SD = 44.78 s; route, SD = 20.63 s; survey, SD = 46.13 s.

The main effect of 'primary/secondary learning' (walk/map condition) was also statistically significant ($F_{1,107} = 31.42$, $p < 0.0001$). The map (18.99 s) condition was faster than the walk (42.77 s) condition. The standard deviations were: walk condition, SD = 52.58 s; map condition, SD = 20.46 s.

Moreover, we found the 'cognitive style participants' × 'primary/secondary learning' (landmark/route/survey × walk/map condition) showed significant interaction ($F_{2,107} = 19.30$, $p < 0.0001$).

Newman–Keuls a posteriori comparisons showed that survey participants were faster in the map condition (21.12 s) than in the walk condition (82.33 s) ($p < 0.001$). In the primary condition, the survey participants took longer than both landmark (28.59 s) and route (17.40 s) participants.

There were no other reliable main effects or interactions in this analysis.

Moreover, in order to disambiguate gender differences from spatial ability differences we performed a five-way analysis of variance for mixed designs with 3 levels of the between-variable 'cognitive style participants' (landmark/route/survey), 2 levels of the between-variable 'gender' (male/female), 2 levels of the between-variable 'primary/secondary learning' (walk/map condition), 2 levels 'directional judgment tasks' (aligned /contra-aligned) and the 8 levels of path repeated factor. We analysed both absolute angular errors and response time.

We did not find any reliable main effect for gender or interaction with the variable 'gender' in these analyses.

4 Conclusions

This experiment was devised to test the hypothesis that the main factor capable of explaining the absence or the attenuation of the alignment effect could be the difference in the three different kinds of cognitive styles used by people to acquire and represent spatial information and not the locomotor experience of the environment in itself. More specifically, we hypothesised that when a person uses a survey cognitive style, that is characterised by allocentric coordinates and by using both egocentric coordinates and landmarks, when they are useful to help one solve a spatial task successfully, the alignment effect should not appear or should be attenuated in accuracy and response time both in primary and secondary learning. In this case, in both conditions (primary and secondary learning) there is a correspondence between encoding and retrieval of spatial information that should make it possible to treat in the same manner the aligned and contra-aligned directional judgment tasks. We also hypothesised that participants who use the route cognitive style would show an alignment effect in secondary learning but not in primary learning; that is, where there is a correspondence between the encoding and the preferred way to represent spatial information, the alignment effect should not appear. Moreover, we hypothesised that landmark participants should show an alignment effect both in primary and secondary learning because their representation is rather poor in spatial components, being based only on figurative characteristics of the landmarks. Indeed, they do not have a clear idea about the right relations among landmarks. There are no conditions where the correspondence between encoding and retrieval of spatial information should appear, because landmark users do not have the ability to use egocentric and allocentric coordinates; for this reason the alignment effect should be always present.

The results seem to support our hypothesis as regards the accuracy but not the response time.

According to the literature, the aligned directional judgment tasks are easier and faster than contra-aligned directional judgment tasks (eg Huttenlocher and Presson 1973; Levine 1982; Presson and Hazelrigg 1984; Presson et al 1989; Roskos-Ewoldsen et al 1998; Richardson et al 1999; Shelton and McNamara 2001a, 2001b, 2001c; Mou and McNamara 2002; Valiquette et al 2003).

However, according to our hypothesis, the judgment of survey participants who were able to use allocentric coordinates and rely on an abstract, internal representation characterised by a bird's-eye viewpoint, but who were also able to use egocentric coordinates and landmarks when they proved useful in solving spatial tasks, remained as accurate as when they were aligned, and even when they were contra-aligned both in primary and secondary learning. If an alignment exists, its size is too small to be confirmed in the current study. These people are able to use both egocentric and allocentric coordinates when they have to solve a directional judgment task, so after primary learning they probably rely on egocentric coordinates in order to solve directional judgment tasks since in this case these coordinates turn out to be the most useful and economic in terms of cognitive sources (encoding and retrieval coincidence) (Tulving and Thompson 1973). However, when these subjects have to solve directional judgment tasks after secondary learning, they probably use the allocentric coordinates because these coordinates are more useful in carrying out the task: in this case, participants had to acquire an abstract spatial representation so it is probable that they represented it in the same way in which they had to learn it, that is in abstract, bird's-eye view based on allocentric coordinates.

As regards response time, survey participants present a speed – accuracy trade-off effect: survey people are more accurate but also on the average take more than twice the time to make their judgments. This effect could be explained by taking into account the characteristics of survey mental representation. This type of representation is a sophisticated structure, which contains different elements, that is landmarks linked by egocentric or allocentric coordinates, that gives its owner an advantage in direction-judging tasks. Therefore, this representation is more complete as regards spatial information, but, on the other hand, survey participants have to consider more information than route (landmarks linked by egocentric coordinates) and landmark (landmarks only) participants when they have to solve spatial tasks.

This makes us think that it produces an advantage for accuracy but not for response time; indeed it produces a greater cognitive load for the visuo-spatial working memory that shows itself in a long response time.

Furthermore, our data support the hypothesis about route people: when these participants are allowed to learn spatial layouts in terms of an intrinsic reference system based on egocentric coordinates (primary learning), they do not show an alignment effect, since they acquire and represent spatial information in the same manner, that is based on egocentric coordinates (correspondence between encoding and retrieval). In fact, acquiring spatial information from multiple experiences with the spatial layout provides multiple vantage points which contribute to making the later usage of the spatial imaging representation easier. This facility does not appear in secondary learning when route participants have to represent spatial information without referring to egocentric coordinates but to an abstract representation based on allocentric coordinates. Our data confirm this hypothesis: the locomotor experience can make spatial information more flexible to use for route participants. Thus, as described by Presson and Hazelrigg (1984), these participants develop route knowledge that is not linked to the specific orientation presented. Therefore, people who represent spatial information in a route style acquire flexibility in orientation by repeatedly experiencing the environment. The use of mental representation is simpler than survey one because it is based on landmarks and a single spatial reference system, that is egocentric coordinates; this allows route participants to be quicker than survey participants in producing direction judgments because in this case the cognitive load on the visuo-spatial working memory is smaller.

Finally, as we hypothesised, the landmark participants, who have poor spatial ability, displayed the alignment effect: they made many more mistakes in contra-aligned directional judgment tasks both in primary and secondary learning. Regardless of the way of learning spatial information, these people do not have enough spatial ability to use it in an appropriate manner for giving contra-aligned directional judgments, because there is no correspondence between encoding and retrieval of spatial information in primary or secondary learning. Probably, the use of a rough mental representation based only on landmarks permits them to give a quicker response than that produced by survey and route people. In this case, the visuo-spatial working memory has not much information to process and this probably results in an advantage in terms of response time but not of accuracy in judging direction.

Our data are based on the idea that the three cognitive styles underlie different cognitive processes (Nori and Giusberti 2003). The landmark style is based on a purely visual component of visuo-spatial working memory that describes the visual features of the environment, such as colour and shape of landmarks, but does not give any spatial information, namely the position of the landmark in relation to the overall array. These results could be interpreted on the basis of the visuo-spatial working memory model of Logie (1995). The dissociation between the visual and spatial components of visuo-spatial working memory is supported by studies conducted both on brain-damaged and normal individuals (eg De Renzi and Nichelli 1975; Hanley et al 1991). For example, Farah et al (1988) described a patient who had great difficulty with mental imagery tasks that involved judgments of visual appearance (eg which is darker blue, the sky or the sea?). However, this same patient had no difficulty with imagery tasks that involved mental action such as imagining and recalling a path between targets. More recently, Wilson et al (1999) described a female patient, a professional sculptor who, following brain damage, was unable to visualise patterns or shapes and to imagine the potential appearance of her sculptures. In contrast, Beschin et al (1997) described a patient suffering from pure representational unilateral spatial neglect. This patient was unable to describe the spatial layout of familiar scenes, leaving out details from what would be his imagined left. He also had a significant difficulty with a task that involved following and remembering a path around Brooks's (1967) matrix. However, he had no difficulty in describing visual properties of scenes, and he did not have general visual problems. Neuroimaging studies have produced evidence for a neural code of human spatial navigation based on cells that respond to a specific spatial location and cells that respond to views of landmarks. The former are present primarily in the hippocampus, and the latter in the parahippocampal region (Ekstrom et al 2003). In addition, studies of normal adults indicate that temporary retention of observed movements (eg Corsi blocks test) appears to use the same parts of the cognitive system as those that are required to generate repeated movements of targets (eg Smyth and Scholey 1994). Retention of visual information, such as abstract patterns or colour information, is characterised by some overlap with the processing of visual perceptual input (eg Logie and Marchetti 1991; Toms et al 1994). From these studies, we can conclude that there is evidence of a component of the cognitive system which retains the visual form of recently presented stimuli, and there is also evidence of a system responsible for retention of movement sequences.

Data obtained by Logie and Pearson (1997) support the idea that route and survey cognitive styles underlie different cognitive processing. In their experiment, participants were submitted to two visuo-spatial tests to support this distinction. One task was Corsi's block test (Milner 1971): the participants had to indicate the correct order of a sequence of blocks. This task requires a strong spatial ability in which the temporal variable is particularly important (ie participants have to remember the absolute and relative position of the blocks). In other words, the participants had to remember the exact route made by the experimenter on the board. In the same experiment, authors used another visuo-spatial test in which participants had to memorise a matrix pattern. In this matrix some cells were filled and the participants had to compare this matrix with another shown successively. The results showed that the two tasks correlated moderately with each other and that they had different developmental trends. This type of dissociation was confirmed by clinical data (eg Cornoldi et al 1999). These results suggest that the manipulation of the sequential/simultaneous presentation of visuo-spatial working memory stimuli to be memorised is an important variable, suggesting a differentiation between sequential and simultaneous processes in visuo-spatial working memory (Pazzaglia and Cornoldi 1999). These differing features between landmark, route, and survey underlie the differences between the cognitive processes that characterise the three spatial cognitive styles.

In conclusion, we agree with our previous conclusions (Nori and Giusberti 2002, 2003) that flexibility in orientation is influenced by the cognitive style used by people, and we agree with Valiquette et al (2003) that the locomotion through an environment does not, by itself, produce an orientation-free mental representation of the environment. This negative conclusion about the role of locomotion in the learning of orientation-independent representation does not imply that locomotion is not important to spatial memory: locomotion facilitates orientation-free retrieval of spatial relations from memory for route people. However, we know that in the walk condition participants experience the layout from multiple perspectives, whereas in the map condition participants experience the layout from a single perspective.

The next step might be to see whether the relationship between flexibility in orientation, cognitive style, and the way of learning spatial information holds true in more complex environment, maintaining a constant body orientation during learning.

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