The role of global and local landmarks in rotations: comparative notes in a planning perspective

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Abstract

The complexity of layout and the arrangement of physical features that define the surrounding environment are still under study in urban planning, architecture and cognitive sciences. Research seems to pay greater attention to wayfinding in complex two-dimensional environments where experiencing disorientation is more common, e.g. in public buildings. The presence of curves or rotations in pathways or the presence of stairs, which structurally introduce turns, seems to compromise the stability of users' cognitive maps because it requires the overlay of both allocentric and egocentric reference systems. In this context, the role played by both local and global landmarks and their position in the layout is crucial for successful wayfinding tasks. Through large-scale pointing tasks, we seek to understand how environmental features influence disorientation and the acquisition of cognitive maps.

The performance of two groups of subjects was compared: the first group approaches the stairs directly on their path, while the second group does so after a 90° turn. The results confirm the importance of geometry as an element capable of significantly affecting the acquisition of cognitive maps

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and show better performance by participants in the first group.

Keywords

Frame of reference, landmarks, spatial cognition, rotation, urban planning

Introduction

The analytical, designing and implementation interest towards spaces of human settlement and relationship has addressed different research perspectives over time. Human agents move in spaces with a high density of knowledge, and in them they must adapt flexibly during their life (Proulx et al., 2016). In land design and planning, this intensity of information often generates problems that are complex and difficult to manage (Denis and Loomis, 2007). An example of complexity in interpreting the spatial behaviors of agents is the challenging difficulty of modeling and simulation in the domains of artificial intelligence and cybernetics. Today, artificial intelligence and cognitive science are intrinsically linked, and therefore the results of AI research are fundamental to understanding the spatial behaviors and decision-making of human agents across usable spaces. For this reason, a correct identification and interpretation of the characteristics of the space can influence spatial decisions, both in terms of navigation support and emotional and perceptual impacts (Zeile et al., 2015). The identification of these fundamental spatial characteristics is complicated by the difficulty of distinguishing between structural and ornamental qualities of space – which is often poorly clarified in spatial analysis. Furthermore, the representation of space changes dynamically over time, too, in ways that are not always predictable (Day and Bartels, 2008; Pouget et al., 2002). The complex articulation of the problems connected to spatial knowledge requires an increasingly interdisciplinary approach that involves psychology, cybernetics, architecture, landscape, as well as different branches of engineering, both on micro-scale spaces (buildings or neighborhoods) and on meso- and macro-scale spaces (cities as mixed sets of settlement spaces and open spaces (Borri and Camarda, 2010; Borri and Camarda, 2013). The relevance of these issues is also linked to a renewed attention to the behavioral aspects of individuals. Certainly, this attention is not recent, having been raised as a criticism of the rational approach in decision theory by Simon in 1955 (Simon, 1955). Yet only recently, thanks to the major technological innovations and agent-based models, a more operational evolution of analytical approaches has become possible. In terms of spatial behavior, navigation devices are, of course, an application of these reflections. From the further point of view of the organization of space, the support that can be offered by these operationally targeted reflections is also relevant. For example, the work developed in terms of so-called space syntax by scholars towards cities and urban regions (Hillier, 2015) is well known. Space syntax contains rather direct links with territorial planning and decision-making - as for example in an urban context it allows the detection of characteristics, spatial hierarchies, accessibility, legibility of urban fabrics and so on. However, space syntax notoriously develops an aggregate approach. That is, it typically considers aspects of perception and interpretation of spaces mediated by paths, relationships, eminently geometric proportions (Hillier and Penn, 2004). There have been attempts to bring space syntax back towards individual disaggregated perspectives but, although interesting, the results are still rather exploratory (Penn and Turner, 2002). The critical problem in these cases is just the lack of importance attributed to the individual behavioral factor. Instead, the spatial behaviors of individual agents notoriously contribute to interpreting and cognitively representing space through a rich and complex amount of information - of great usefulness for spatial planning and decision-making.

However, the spatial behavior of agents navigating the spaces available to them is not a simple topic in terms of decryption. It needs refined analytical approaches that are able to analyze the individual components of personal spatial cognition and personal relationship with spaces. In this context, the complex relationship between planning and spatial decision-making is evident, with the evident differences in analytical scale. In fact, spatial planning is typically oriented towards organizations of spaces on an urban, supra-urban or neighborhood scale - which are large spaces. Behaviors, on the other hand, are typically developed by single agents towards small-scale spaces. A connection problem therefore arises between the different scales that is able to enhance needs and behaviors - first analytically and then operationally. For this reason, the small scale of spatial behaviors is an unavoidable level in a process of understanding and managing spatial behaviors towards territorial planning activities (Lei et al., 2009).

Due to these difficulties, structural research on the aspects of connection between spatial cognition and spatial planning is rather little explored. However, a reflection that allows the development of small-scale analyzes towards different classes of agents is today possible thanks to the current knowledge and possibilities of information technology. Reflections can then be oriented towards re-aggregation processes towards a broader dimension which is typical of spatial planning (Cohen, 2013). As an example, analyses of individual spatial cognition in the navigation of urban spaces have allowed reflections on the reorganization of the activities and functions of urban spaces in city regeneration plans (Mastrodonato et al., 2022). In other cases of spatial behavior at the microscale in city spaces, the analysis was able to draw information regarding the complex accessibility problems of the cities themselves (Manley et al., 2021). It is therefore rather evident the full legitimation of analyzes regarding multi-agent spatial cognition carried out at a small-scale level in the research fields of spatial planning and decision-0making.

The work presented here is developed in this context. The small-scale dimension referring to the navigation activities of individuals within urban spaces is the object of this research. In particular, in this case it is an interest developed within confined (built) environments. The city is made up of a variety of confined and unconfined spaces, and within them citizen agents act at various moments and situations of their days. There are confined and non-confined areas such as buildings, public parks, empty areas adjacent to the compact city - which are all affected by the activities of individual agents in a reiterated, intermittent or even episodic manner, over time. On the other hand, there are areas that are affected by spatial relations of cognitive interaction on the part of agents in a much more stable and long-lasting manner over time. The typical case of the latter is the residential house. However, functions and relationships expressed by spatial behaviors in this case are poorly assorted and therefore less able to represent a multifunctional scalar context and multiform spatial relationships like a city. For this reason, the reference level of the investigation carried out in this article includes meso-scale elements, rather than just microscale ones. In fact, it is developed within a confined area, a public access building, but with the particularity of developing diversified spatial behaviors towards the internal space, towards the external spaces and over time. The public building of this reflection is a university building and in particular allows a more in-depth and refined reflection of the aspects of the cognitive relationship between agent and space. The structural and widespread presence of staircase connectors allows us to reflect on a rather emerging problem. This is orientation, as a factor of structural characterization of the cognitive relationship between the agent and space. A reflection on the problem of orientation can generate useful results towards an extension of the complex and differentiated problems of spatial cognition within a broader urban and territorial scale. The remainder of the paper is structured as follows: Section 2 describes the theoretical framework in which the work presented here is placed through an in-depth review of the literature on landmarks and their impact on the acquisition of spatial knowledge during an orientation task. To achieve this goal, the authors compare the performance of users performing such tasks in different indoor layouts, the experiment is described in Section 3. Section 4 analyzes the results individually while Section 5 discusses the main results; Section 6 summarizes and concludes.

The Role of Landmarks in Wayfinding Tasks

Background

The design of spaces properly conceived in terms of usability, functionality, readability, and pleasantness is the subject of study in various disciplines, each with its own analysis from its perspective. Whether indoor or outdoor spaces, the key element is identifying the ways in which the environment is experienced by agents, the extent to which its configuration can influence orientation and understanding of it. It is now recognized in literature that wayfinding is an interactive process between agent and environment, and understanding this interaction is fundamental to develop predictive models of human behaviors (Allen, 1999; Raubal and Egenhofer, 1998; Dubey et al., 2019). To this end, it becomes a priority to recognize the presence of elements that enhance readability by reducing the sense of disorientation that occurs when one loses his own references (Röser et al., 2011; Siegel and White, 1975).

Humans seem to use different navigation strategies, successfully integrating them and skillfully resorting to simplified strategies. The criteria adopted by agents moving in built spaces are dictated by precise choices that shape their behavior, stemming from numerous factors such as destination, purpose of the trip, planned stops, itinerary, configuration of environments, personal preferences, culture, background, familiarity, and everything that is seen and perceived in the environment (Skorupka, 2010; Golledge and Gärling, 2002; Meilinger et al., 2008; Conroy Dalton and Hölscher, 2012; Dubey et al. 2019). Their approach to complex tasks requires evaluating available strategies to reduce the number of elements that must be considered simultaneously and lighten cognitive load. For example, to reduce complexity, human agents are able to structure spatial information hierarchically, adopting *coarse-to-fine* or vice versa abstraction processes and subdividing into different sub-tasks to be performed in a precise temporal order (Tenbrink and Seifert, 2011). The ability to process patterns simultaneously and to easily switch between levels of hierarchy allows them to develop their cognitive maps by extracting only the most important information. Common sense, or *basic reasoning*, thus allows the adoption of simplifying strategies. The problem is understanding how humans conceptualize a map when planning a route, and therefore in the absence of direct access to the real world, and how they develop this ability to move between levels in relation to the task to be performed and the scale at which that task is conceived. Each level (planning, instruction, driving) involves specific tasks and inherits properties from higher levels while possessing its own (Timpf et al., 1992). Antonini (2005) also recognizes a hierarchy adopted in pedestrian movements where decisions are made at higher or *strategic* levels and *tactical* levels establish a temporal order of actions defined at a higher level. At these conceptual levels, which take into account times, distances, safety, comfort, follows an *operational* level where, referring to choices made in previous phases, instantaneous and personal decisions are made taking into account numerous other factors such as the presence of other pedestrians, the surrounding environment, and so on. The definition of levels or categories, which fulfill fundamental tasks, acts as a "principle of organization of the representation system" to allow the retrieval of information through inferential processes, allows the recognition of criteria that allow subdivision into classes characterized by possessing or not specific characteristics. This facilitates the recognition of common elements or the prediction of behaviors or responses with respect to each class as well as the simplification of their analysis. The importance of categorization processes lies in the possibility of using organizational principles to order elements into sets (Brandimonte, 2004).

However, during navigation, a series of relationships are created between us and the surrounding objects that are constantly changing and derive from the direct interaction of the body with the environment in terms of proprioceptive and perceptual visual flows. In fact, we store information learned through our experience and perceptions by defining a primary frame of reference (SFR), based on our own body, called *egocentric* (Golledge and Gärling, 2002). The surrounding environment, on the other hand, in its allocentric representations (Golledge, 1999), refers to global coordinates and stable, prominent elements, defined as *landmarks*. It is precisely these that enhance its readability and navigability (Röser et al., 2011; Gillner and Mallot, 2008; Credé et al., 2019; Credé et al., 2020; Philbeck and O'Leary, 2005). According to Tversky (2003), in all spatial processes it is necessary to define frames of reference with respect to which to allocate objects in space relative to each other with reference to local or global elements. However, these relationships remain qualitative and categorized. It follows that during the orientation process, it is essential to establish a correspondence between the subjective frame of reference, centered on the individual in motion, and the allocentric, objective, global system specific to the environment. To this end, additional operations such as physical or imaginary rotations are necessary to establish such alignment (Péruch and Lapin, 1993). Mental operations of recalling spatial information are simple when the motions made are mere translations; more serious problems may arise when rotations need to be performed as they imply physical or mental efforts (Levine, 1982). Difficulties arise regardless of whether the environment or the individual is rotated with respect to the map, real or cognitive (Montello, 2010); however, the significant impact that this type of transformation has on navigation and subsequent disorientation during wayfinding tasks is now recognized. Pointing ability, in fact, is not influenced by physical or imagined translations but deteriorates after physical rotations and even to an increasing extent if rotations are only imagined (Risier, 1989; Kelly and McNamara, 2008; Shepard and Hurwitz, 1984; Presson and Montello, 1994). This is probably because one must imagine a different perspective and then align it, through a rotation of the frame of reference, to the position where one imagines being (Péruch and Lapin, 1993; Huttenlocher and Presson, 1973).

This results in a reduction in the accuracy of pointing tasks, as well as an increase in the time required to perform them, to allow the processes necessary for aligning the two reference systems. Obviously, translational motions do not imply this type of cognitive effort, and access to *object-to-object* relationships is immediate without the need to infer them through a *self-to-object* relationship (Easton and Sholl, 1995; Gagnon et al., 2014; Presson and Montello, 1994).

We propose to investigate and eventually compare the performance of agents when some aspects of the layout are modified, even slightly, in order to identify the elements that create difficulties and that are more difficult to correctly implement in their cognitive maps. The assessment of orientation ability has been carried out through pointing tasks at both local and global landmarks. This classification aims to understand if these two types of landmarks are allocated in different SFRs and what role they play in improving navigation.

With this purpose, in the present work, the consequences induced by the use of stairs, which structurally implement rotations, were investigated. Our hypothesis is that such disorientation may be the consequence of the effects of rotation that are probably performed without being perceived as such. Through a series of experiments conducted at the Polytechnic University of Bari, the performances of environment users who approached the stairs directly on their walking path or encountered the stairs after a turn were investigated.

The aim is to assess to what extent the position of this element relative to the layout can increase disorientation and the role that local and global landmarks play in such processes.

A Literature Review

Identifying the correspondence between prominent features of the environment and spatial information, expressed in an allocentric system, on a map or mental representation, is the crucial element in the process of spatial orientation as a foundation for successful navigation (Gagnon, 2014) It is natural to wonder if there are elements that influence navigation in unfamiliar cities. Peters (2012) hypothesizes that some elements are better suited to adapt to our mental representations because they are closer to our way of decoding and processing information. According to Golledge and Gärling (2002) the readability of a route, its ability to become known through the distinguishing elements, significantly influences the ability to be learned by navigators and is based on the number of relevant aspects encountered along the way. On the other hand, spatial abilities are the product of numerous factors: cultural, social, political, individual cognitive abilities; reading maps, photos, freedom of choice, previous experiences influence the decision-making process. The authors (Golledge and Gärling, 2002) conclude that everyone encodes spatial information differently. However, it is possible to recognize some common steps in the process of acquiring spatial knowledge. They argue that the first step is the knowledge of landmarks, which allows only the ability to recognize familiar environments but not to move between them by autonomously processing a route; in this phase, knowledge is defined as *declarative* and encompasses all spatial information contained in long-term memory: places (landmarks), lines (paths, boundaries), areas (neighborhoods, districts, cities, regions). This is followed by *route knowledge* (or *procedural*) in which different segments are ordered in such a way as to be able to move from one point to another, defining the rules for wayfinding and navigation in the experienced space. It is acquired through exploration in the egocentric SFR but does not allow the acquisition of awareness of the layout of the environment (Satalich, 1995). This seems to characterize the last stage known as *configurational knowledge* (Golledge and Gärling, 2002). This knowledge can be acquired through multiple explorations using different routes (Satalich, 1995) or by integrating spatial information piece by piece; consequently, it can be inferred from spatial primitives characteristics even if not directly experienced; the perspective is allocentric. In other words, it represents our ability to infuse meaning into space as we experience it. It seems to be the most comprehensive type of knowledge (Ishikawa, 2008; Ishikawa and Montello, 2006; Montello, 1998; Mou and McNamara, 2002).

The acquisition of the three types of knowledge does not necessarily have to be sequential as it might appear at first glance. According to Montello (1998), configurational knowledge can sometimes be acquired after just a few explorations, while there are residents who even after several years in the same neighborhood are only able to navigate specific routes. The acquisition of route knowledge also does not necessarily imply the acquisition of configurational knowledge; Siegel and White (1975) argue that during learning through navigation in the environment, the first forms of knowledge acquired are landmarks and route knowledge, only later is one able to deduce configurational knowledge from them. It follows that landmarks are fundamental for the construction of our cognitive maps and that route knowledge represents the ability to process a route between them, ultimately a subsequent step.

In literature, the role of landmarks in supporting navigation is still under investigation, and the classification itself is quite controversial; it is agreed to recognize them as the first elements to be used for orientation, only later are elements added to complete cognitive maps. According to Röser *et al.*

(2011), it is possible to attribute them *visual importance*: with reference to all the features captured by the human eye, such as size, color, shape, and so on; *semantic importance* related to the importance of the building in the collective imagination: Colosseum, Big Ben, or its functional or cultural importance that make it prominent compared to the surrounding environment, for example, a church or a historical monument. In this sense, they have the ability to increase the importance of places, making them familiar even to those who have no experience of them, to the extent that these landmarks are commonly referred to for giving directions. Finally, *structural importance* is more properly referred to the importance that the landmark could have during navigation, for example, its position at a certain intersection, the possibility of representing a decision point. Their experiment seems to show that navigators use landmarks differently although they recognize the need, for the purpose of supporting navigation, to place them in strategic positions. Their role is fundamental when there is not great familiarity with the surrounding environment and recourse to external references is necessary. With increasing familiarity, the importance of global information decreases in favor of specific individual experiences, so people tend to orient themselves more by referring to local experiences or their own memory, rather than to global environmental structures or landmarks.

In the literature, there is also recognition of a link between the type of landmark and the adoption of a particular frame of reference. According to Gillner and Mallot (1996), (1998) when global coordinates such as global landmarks are adopted, movements are dictated by the recognition of places regardless of the observer's gaze direction. This place-based approach is countered by the *view-based* one in which movements, represented in egocentric coordinates, are dictated by the recognition of *views* rather than *places*. The authors recognize the influence of landmarks in *recognition-triggered response*, where a certain action is performed when a place is reached and a landmark is recognized. In addition, it seems that individuals, when recognizing a landmark, are tempted to repeat the same independent goal pursued, i.e., a considerable part of them base their decisions on simple view associations. This phenomenon known as *persistence* seems to occur frequently. In a wide range of experiments, in a virtual environment, cited by the authors, it is shown that by moving landmarks after learning the route, the behavioral response is dictated by their recognition, not by the configuration of objects in the place. Ultimately, after learning a route, at a decision point, movements are triggered by the recognition of the landmark, neglecting the configurational arrangement. Golledge (1992) also recognizes in the interactive nature of the wayfinding process the ability to recognize a place, and therefore to remember it, in relation to the presence of significant elements that contribute to making it more easily and efficiently memorized. In such tasks, the ability to recognize elements that can serve as anchor points, potentially allowing the correction of the route when mistakes are made, plays a fundamental role. The type of information required for this purpose will depend on the complexity of the layout or path; monotonous environments with similar repeating features can make wayfinding very challenging and, in such cases, may require additional information.

Finally, once the environment is learned, in our daily experience, we may find ourselves in the situation of having to perform new navigation tasks, or simply having to remember it for a multitude of purposes. In this case, it is necessary to resort to a mental operation called *recall* (Peters, 2012). In fact, it involves recalling to mind the information stored in the internal representation, not perceptibly available, and extracting it as if facing a real map. The crucial operation to remember the route, or to allocate oneself in the mental representation, is then the identification in memory of the prominent elements of the environment or the points that required decisions.

The case study

It is widely recognized that navigation in public buildings such as airports, university departments, or hospital wards is more complicated, and experiencing orientation loss is more common. To date, an enormous body of research has been focused on wayfinding, almost always with reference to navigation in two-dimensional environments; only recently greater attention has been paid to investigating multi-floor environments (Hölscher et al., 2006). Probably, the complication arises from having to consider the effects of rotational movements, which necessarily come into play in this case. The presence of turns, stairs, for instance, implies the use of different SFRs that need to be overlapped, requiring greater cognitive effort than when performing simple translational movements. Hölscher *et al.* (56) argue that people easily experience disorientation after using stairs, probably due to the assumption, not always correct, that once reaching the top, they will face the initial direction. However, under the same conditions, such an assumption can also lead to gross errors. Another common assumption, not always justified, is that the configuration of the floors is always the same.

According to this theoretical framework, experiments have been conducted in this study to examine the effects of rotations induced by the presence of stairs on users' performance when they are placed directly in their walking direction or when they are forced to make a 90° turn to use them. The aim is to investigate how the shape of built environments and the presence of landmarks, global or local, influence people's spatial knowledge in different places. The hypothesis is that when stairs are encountered directly along one's path, the performance of large-scale pointing tasks is better because once at the top, finding oneself in the same initial walking direction, egocentric and allocentric SFRs do not conflict.

According to Hintzman et al. (1981), it is assumed that the cognitive maps built up during navigation are not rotated, rather participants trying to allocate the position of targets in relation to their own position, tend to mentally scan the pathway without any regard for the rotations. Landmarks are used for this purpose (Gardony et al., 2014; Huttenlocher and Presson, 1973; Shepard and Metzler, 1971; Shepard and Cooper, 1982). The distinction between global and local landmarks aims to understand if there are differences between these two types, if the processes underlying the construction of mental maps are the same, and if some are preferred over others.

It is hypothesized that individuals adopt different SFRs for the two types of landmarks, as it is believed that movements may be perceived differently with respect to them. In fact, global landmarks could refer to a configurational (survey) knowledge of the area that could facilitate the recall of mental rotations. On the other hand, local landmarks, perceived as close, could imply the use of *self-to-object* relations in evaluating the relationship between oneself and these landmarks (Etienne and Jeffery, 2004; Philbeck and O'Leary, 2005; Risier, 1989; Kelly et al., 2008). It implies that spatial relations with respect to the two types of landmarks may be perceived differently, as if different SFRs are adopted on different scales. To assess these differences, participants are administered various pointing tasks performed at different points in the building after traversing the stairs.

Participants

The experiment reported in this work was preceded by a pilot study, entirely analogous to the one presented here, conducted in the MZK building of the Bremen Campus, with the only difference being that in that case the layout of the floors changed, which may have somewhat made it less easy for participants to perform the pointing tasks. Of course, these considerations were taken into account in the analysis of the results carried out; however, the results are not reported here for reasons of synthesis, and because the sample was not sufficiently significant for a statistical investigation, therefore the evaluations were qualitative.

In the experiment reported here, seventy-seven students recruited from the Polytechnic University of Bari participated as volunteers, randomly divided into two groups. The first, in which the stairs were encountered facing the walking perspective, consisted of 17 women and 22 men, for a total of 39 participants, aged between 20 and 29 years; the second, in which the stairs were encountered after a 90° turn, consisted of 38 participants, including 15 women and 23 men aged between 21 and 29 years. In the latter case, the results relating to 2 participants were excluded because they did not complete the last retrieval task. The prerequisite was that they were not familiar with the building in which the task was performed but were familiar with the surrounding environment. This assessment was made using a Likert scale from 1 to 10, considering values of familiarity less than 5 for the building and greater than 5 for the Campus as negligible. The data were reported in the final questionnaire; different data were not taken into consideration. Participants were never allowed to rotate or move their bodies although often required.

Procedure

Before starting, participants were told that a research was being conducted to investigate navigation skills in the presence of complex paths, to assess how spatial relationships between elements (landmarks) in space are encoded, stored, and remembered, and that their task was to indicate the position of landmarks in the environment.

They were told that they would be asked to point out some landmarks, both local ones present in the building and global ones in the Campus, or cardinal directions. They were not informed about the correctness of their answers.

The data collection for pointing tasks was done by asking participants to report the positions of each target on a sheet with a circle of diameter 12 cm, held horizontally on a rigid support by each participant. The center of the circle, indicating the participant's position, was marked on the circle, and on top of the circle was reported the word *front*, indicating the direction they were facing. They were asked to indicate the direction of the target by drawing a straight line from the center (themselves) to the hypothesized position of the target. Before performing the pointing task, they were exactly explained the procedure to follow, and at the starting point, they received training during which the experimenter repeated the questions about the positions of the targets until they declared they were sure they had learned them. The experimenter's verification was done by asking them to report on a single circle, on the same sheet, the positions of all landmarks, which the experimenter verified to be correct by comparing them with a diagram correctly constructed. Errors of 5° clockwise or counterclockwise from the correct position of the landmark were tolerated. In this way, participants understood the spatial relationships between the individual landmarks and their position in relation to them. They were then asked to explain how to solve the task to make sure the procedure had been learned, and that the pointing should be done as quickly as possible without compromising accuracy. The instructions were to ignore both the vertical dimension of the building and the different heights of the landmarks but to consider them all at the same (Richardson et al., 1999).

At each point where the large-scale pointing task was performed, they were asked to indicate the direction of the targets relative to theirs. This was done by handing out a number of sheets equal to the number of targets to be pointed out. On each of them the circle was drawed reporting the *front* direction. The use of different sheets for each target was aimed at preventing them from simply reproducing the initial scheme. For the same purpose, the experimenter called out the landmarks in random order. For each target, accuracy was evaluated as the angular difference, in absolute value, between the given response and the correct direction of the target. The experiment was conducted individually for each participant, and each of them had to follow the experimenter along the path (Montello, 1991; Xiao and Zhang, 2013). The last phase of the experiment investigates the *recall* of information. At the end of the navigation through the building, participants were led to a windowless room in another building and were asked to imagine themselves standing with their backs to the elevators and to reproduce on different sheets the position of each landmark called by the experimenter with reference to the position they were asked to imagine themselves. In this case, the participants were seated, and the sheets were placed horizontally on a table.

At the end of the experiment, they had to fill out a general questionnaire about the experiment, the adoption of mnemonic strategies, the presence of targets that were more difficult to point out, and familiarity with the building and the surrounding environment. The targets were chosen because they were prominent elements of the environment. The stopwatch was started when the landmark was called out, and it was stopped as soon as the participants lifted the pen from the sheet. The targets inside the building were, respectively, for the group that encountered the stairs directly on their walkway, a large geographic map (Cartina) positioned on the wall of a corridor on the second floor and the entrance of the Department of Architecture (Ingresso Edificio); for the group that encountered the stairs after the turn, again the entrance of the Department of Architecture (Ingresso Edificio) and the entrance to the Department of Structures (Ingresso Strutture) connected to the first via a short open passage from which, however, due to the presence of other buildings, it is not possible to see the landmarks. The Cartina could not be chosen as a target in the second experiment because it was not encountered along this path. The external targets were:

1. an entrance to the Campus in Orabona street;
2. a secondary entrance in Re David street;
3. a piezometric tower of considerable height mushroom shaped (Fungo), easy to notice;
4. the North.

The experiment, performed by all participants, took place through two floors of the building housing the Department of Architecture of the Polytechnic University of Bari, lasting about 30 minutes. The building is a four-floor building, whose configurations do not change from floor to floor.

The participants in the first group, encountering the stairs on their way, enter the Department of Architecture directly, are taken up using the elevator to the second floor of the building. The use of the elevator avoids walking up the stairs more times than necessary for the experiment to avoid becoming familiar with the building structure and making more rotations than necessary. Once on the second floor, the experimenter guides the participant immediately outside the stairwell where, in the large central atrium accessing the two wings of the building, a wall completely windowed is positioned, from which only some landmarks are visible. On the left side wall is placed the large map (Cartina) serving as a local landmark (Fig. 2). Facing the windows, they are first asked to manually point out all the targets until the experimenter is sure they are perfectly aware of their position in the Campus; then they are asked to reproduce the scheme on the circle on a single sheet. The operation is repeated until the experimenter is certain that the positions of the landmarks are clear to the participant. The participant is then led back to the stairs, which are almost on the same direction of his/her walkway.

The stairs are climbed until reaching the third floor, where a first pointing task is performed in the stairwell. This compartment is a rectangular structure completely surrounded by walls without windows. The pointing is performed in such a way that the position they face is actually the initial one; immediately out of the stairwell, a left turn is run so as to the participants will be facing a direction rotated by 90° counterclockwise with respect the initial one (Fig. 4). While walking along this segment, the participant again crosses the wide atrium corresponding to that of the lower floor, and completely similar to it, where the learning phase had done, although the window shutters are kept closed, not allowing an external view. Here, a new large-scale pointing task is performed, following the same procedures. After few meters, the participants make a right turn, which effectively brings them to face the initial position, and they perform the last large-scale pointing task.

Figure 1 - Map of the Campus in Bari and targets' position

Figure 2 - Location of Cartina on the wall of the atrium at the 2° floor of the piano del Department of Architecture

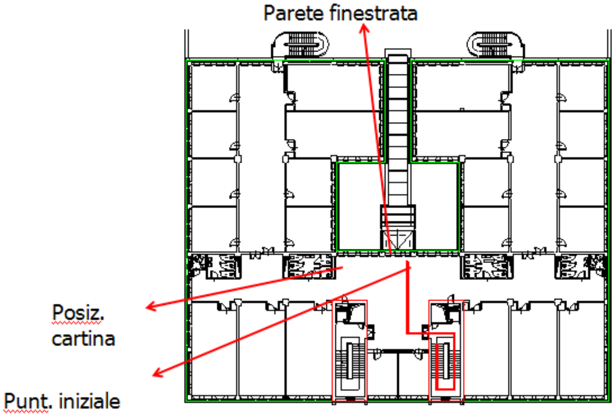


Figure 3 - Plan of the 2nd floor of the department of Architecture and tracking paths

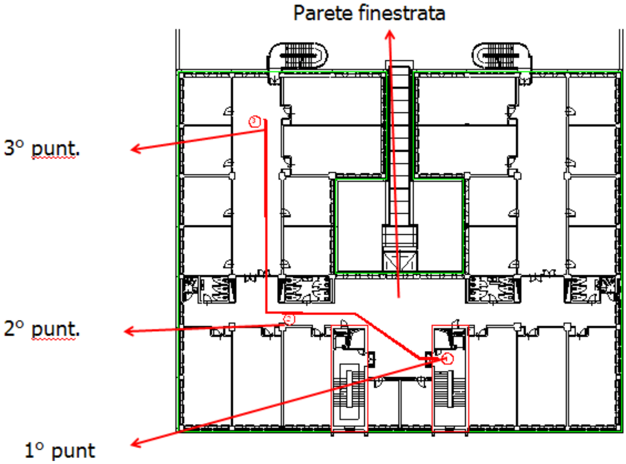


Figure 4 - Testing locations on the 3rd floor

Figure 5 - Second testing location

The procedure for participants in the second group is conceptually the same, but the path will obviously be different.

Participants are led into the building housing the Department of Structures, immediately adjacent to the Department of Architecture where the experiment takes place. The purpose is to allow the approach to the stairs after a 90° turn respect to the walking direction. They move from one structure to the other through a short outdoor passage from which, due to the presence of other buildings, no landmark can be seen. Immediately before entering the Department of Structures, participants attend the learning procedure. Some targets are not visible, as it was in the previous cases. At this stage, the last local target, Ingresso Architettura, cannot be learned, and it will be integrated as soon as it is reached. They will turn their backs to both entrances so that the learning phase is in the same direction faced by the participants in the first group. This makes the comparison easier. Once the experimenter is sure that the

participant has a correct awareness of the positions of the targets, they are guided through a corridor that is almost straight in relation to its length, towards the Department of Architecture. Once the entrance is reached, the participant is asked to take it into account and the whole learning procedure is repeated in order to integrate it.
Subsequently, they take the stairs, which are no longer in the walking direction but require a right turn. The first pointing task is performed in the stairwell on the first floor, finding themselves once again facing the starting position. Immediately outside the stairwell, on the first floor, they walk the same route and perform the same pointing tasks as in the previous case, as the configuration of the floor is the same from floor to floor.

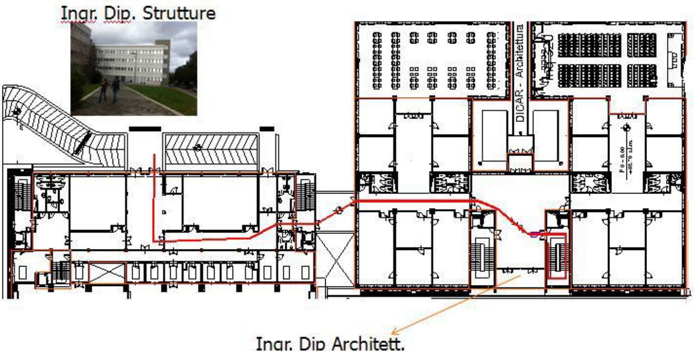


Figure 6 - Path walked by the participants in the 2nd group

Both accuracy in pointing and latency were measured to establish the possible effects of disorientation from a different approach to the stairs. The former is a powerful measure of configurational knowledge (Richardson et al., 1999), the latter allows to understand if there are differences among the different landmarks and how the stored information is easily accessible (Montello, 1991).

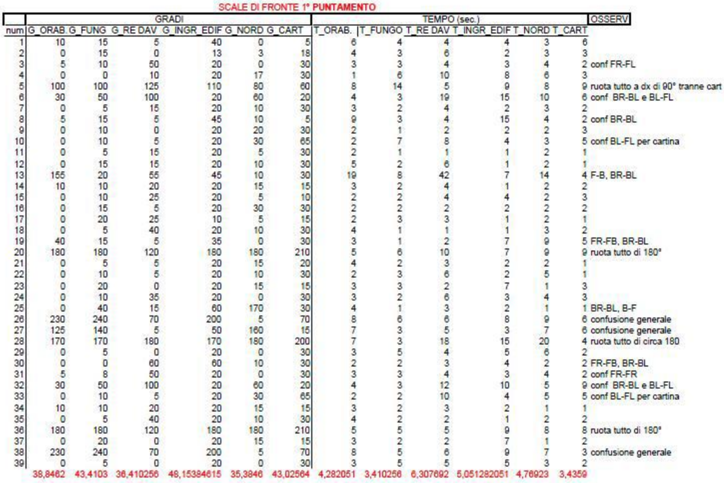
Analysis of Data

In this section, we compare pointing errors to test differences in accuracies between the direct approach to stairs and the approach after turning and the differences in latencies regarding the different targeted landmarks. The hypothesis we assume is that approaching the stairs along the walking direction induces fewer errors and facilitates orientation; we also observe if there are differences in pointing to different targets with particular regard to the differences between global landmarks, including the North, and local landmarks namely those within the building. The aim is to of verify their influence on cognitive maps that involve rotations or turns. In particular, if taking the stairs involve a 90° turn, it is possible that such errors would be reflected in pointing.

Latencies have also been observed, representing a good method for evaluating access to stored information.

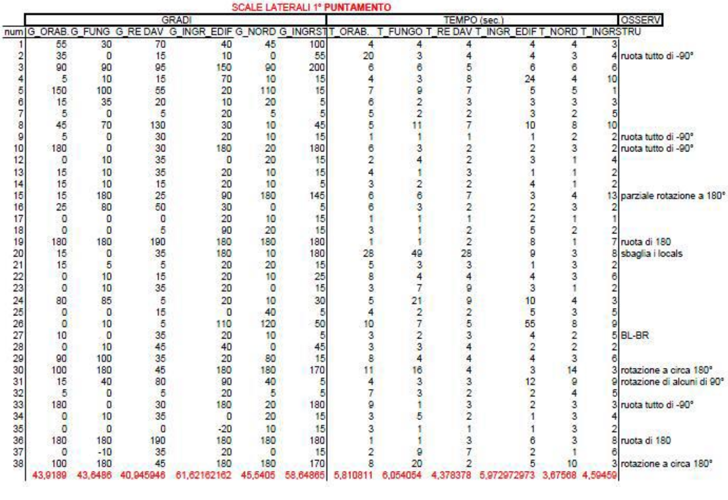
The first pointing task is carried out in the stairwell for both the participants of the first and second group, with the observed landmarks being the same except for the Cartina and the Ingresso Strutture. A comparison within each group will be made for these two landmarks. The position they face is the same as the learning phase.

The absolute values of errors in the two approaches were compared using a one-way ANOVA analysis on the degrees and direction of approach to the stairs (front, side). The result for the first pointing provides a value of $p = 0.431 > 0.05$, which is not statistically significant, indicating that there is no substantial difference between the groups. Regarding latencies, the one-way ANOVA analysis between response time and approach direction provided a value of $p = 0.000$.



SCALE DI FRONTE 1° PUNTAMENTO

	GRADI						TEMPO (sec.)						OSSERV
num	G_ORAB.	G_FUNG	G_RE DAV	G_INGR_EDIF	G_NORD	G_CART	T_ORAB.	T_FUNGO	T_RE DAV	T_INGR_EDIF	T_NORD	T_CART	
1	10	15	5	40	0	5	6	4	4	4	3	6	
2	0	15	0	13	3	18	4	3	6	2	3	3	
3	5	10	50	20	0	30	3	3	4	3	4	2	conf FR-FL
4	0	0	10	20	17	30	1	6	10	8	6	3	
5	100	100	125	110	80	60	8	14	5	9	8	9	ruota tutto a dx di 90° tranne cart
6	30	50	100	20	60	20	4	3	19	15	10	6	conf BR-BL e BL-FL
7	0	5	15	20	10	30	3	2	4	2	3	2	
8	5	15	5	45	10	5	9	3	4	15	4	2	conf BR-BL
9	0	10	0	20	20	30	2	1	2	2	2	3	
10	0	10	5	20	30	65	2	7	8	4	3	5	conf BL-FL per cartina
11	0	5	15	20	5	30	2	1	1	1	2	1	
12	0	15	15	20	10	30	5	2	6	1	2	1	
13	155	20	55	45	10	30	19	8	42	7	14	4	F-B, BR-BL
14	10	10	20	20	15	15	3	2	4	1	2	2	
15	0	10	25	20	5	10	2	2	4	4	2	3	
16	0	15	5	20	30	30	2	2	2	2	2	2	
17	0	20	25	10	5	15	2	3	3	1	2	1	
18	0	5	40	20	10	30	4	1	1	1	3	2	
19	40	15	5	35	0	30	3	1	2	7	9	5	FR-FB, BR-BL
20	180	180	120	180	180	210	5	6	10	7	9	9	ruota tutto di 180°
21	0	5	5	20	15	20	4	2	3	2	2	1	
22	0	10	5	20	10	30	2	3	6	2	5	1	
23	0	20	0	20	15	15	3	3	2	7	1	3	
24	0	10	35	20	0	30	3	2	6	3	4	3	
25	0	40	15	60	170	30	4	1	3	2	1	1	BR-BL, B-F
26	230	240	70	200	5	70	8	6	6	8	9	6	confusione generale
27	125	140	5	50	160	15	7	3	5	3	7	6	confusione generale
28	170	170	180	170	180	200	7	3	18	15	20	4	ruota tutto di circa 180
29	0	5	0	20	0	30	3	5	4	5	6	2	
30	0	0	60	60	10	30	2	2	3	4	2	2	FR-FB, BR-BL
31	5	8	50	20	0	30	3	3	4	3	4	2	conf FR-FR
32	30	50	100	20	60	20	4	3	12	10	5	9	conf BR-BL e BL-FL
33	0	10	5	20	30	65	2	2	10	4	5	5	conf BL-FL per cartina
34	10	10	20	20	15	15	3	2	3	2	1	1	
35	0	5	40	20	10	30	4	2	2	1	2	2	
36	180	180	120	180	180	210	5	5	5	9	8	8	ruota tutto di 180°
37	0	20	0	20	15	15	3	2	2	7	1	2	
38	230	240	70	200	5	70	8	5	6	9	7	3	confusione generale
39	0	5	0	20	0	30	3	5	5	5	3	2	
	38,8462	43,4103	36,410256	48,15384615	35,3846	43,02564	4,282051	3,410256	6,307692	5,051282051	4,76923	3,4359	

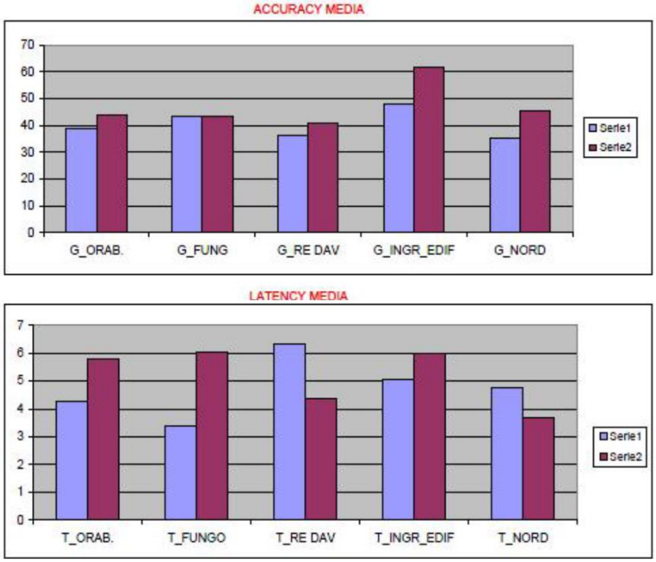


SCALE LATERALI 1° PUNTAMENTO

	GRADI						TEMPO (sec.)						OSSERV
num	G_ORAB.	G_FUNG	G_RE DAV	G_INGR_EDIF	G_NORD	G_INGRST	T_ORAB.	T_FUNGO	T_RE DAV	T_INGR_EDIF	T_NORD	T_INGRSTRU	
1	55	30	70	40	45	100	4	4	4	4	4	3	
2	35	0	15	10	0	55	20	3	4	4	3	4	ruota tutto di -90°
3	90	90	95	150	90	200	6	6	5	6	6	6	
4	5	10	15	70	10	15	4	3	8	24	4	10	
5	150	100	55	20	110	15	7	9	7	5	5	1	
6	15	35	20	10	20	5	6	2	3	3	3	3	
7	5	0	5	20	5	5	5	2	2	3	2	5	
8	45	70	130	30	10	45	5	11	7	10	8	10	
9	5	0	30	20	10	15	1	1	1	1	2	2	ruota tutto di -90°
10	180	0	30	180	20	180	6	3	2	2	3	2	ruota tutto di -90°
12	0	10	35	0	20	15	2	4	2	3	1	4	
13	15	10	35	20	10	15	4	1	3	1	1	2	
14	15	10	15	20	10	5	3	2	2	4	1	2	
15	15	180	25	90	180	145	6	6	7	3	4	13	parziale rotazione a 180°
16	25	80	50	30	0	5	6	3	2	2	3	2	
17	0	0	0	20	10	15	1	1	1	2	1	1	
18	0	0	5	90	20	15	3	1	2	5	2	2	
19	180	180	190	180	180	180	1	1	2	8	1	7	ruota di 180
20	15	0	35	180	10	180	28	49	28	9	3	8	sbaglia i locals
21	15	5	5	20	20	15	5	3	3	1	3	2	
22	0	10	15	20	10	25	8	4	4	4	3	6	
23	0	10	35	20	0	15	3	7	9	3	1	2	
24	80	85	5	20	10	30	5	21	9	10	4	3	
25	0	0	15	0	40	5	4	2	2	5	3	5	
26	0	10	5	110	120	50	10	7	5	55	8	9	
27	10	0	35	20	10	5	3	2	3	4	2	5	BL-BR
28	0	10	45	40	0	45	3	3	4	2	2	2	
29	90	100	35	20	80	15	8	4	4	4	3	6	
30	100	180	45	180	180	170	11	16	4	3	14	3	rotazione a circa 180°
31	15	40	80	90	40	5	4	3	3	12	9	9	rotazione di alcuni di 90°
32	5	0	5	20	5	5	7	3	2	2	4	5	
33	180	0	30	180	20	180	9	1	3	2	3	3	ruota tutto di -90°
34	0	10	35	0	20	15	3	5	2	1	3	4	
35	0	0	0	-20	10	15	3	1	1	1	3	2	
36	180	180	190	180	180	180	1	1	3	6	3	8	ruota di 180
37	0	-10	35	20	0	15	2	9	7	2	1	6	
38	100	180	45	180	180	170	8	20	2	5	10	3	rotazione a circa 180°
	43,9189	43,6486	40,945946	61,62162162	45,5405	58,64865	5,810811	6,054054	4,378378	5,972972973	3,67568	4,59459	

Table 1 - Comparison between mean errors, in absolute value, during the 1st pointing

Table 1 reports errors in terms of angular deviations taken in absolute value, with errors of 5° being tolerated. Although the errors made by participants in the second group are almost always higher (except for the Fungo), as revealed by the ANOVA analysis, there are no significant differences between the participants in the two groups. However, those who made errors report a clear rotation of the map by 90°, indicating a lack of attention to the turn to take the stairs, or by 180°, thus imagining themselves in the opposite direction with respect to that of the departure. It is again as if the stairs were in the walking direction and erroneously imagining facing the starting position once reaching the top. It is as if they confused the Front-Back axis in this case, performing a procedure known in the literature as mirroring. In fact, spatial relationships are mirrored relative to their F-B axis; the cognitive processes underlying this phenomenon are not yet perfectly clear; however, it is reported that errors of this type are of a different nature compared to the others (Kozhevnikov and Hegarty, 2001).


ACCURACY MEDIA

LATENCY MEDIA

Figure 7 - Comparison between the mean errors in absolute value in the 1° pointing of the accuracies and latencies

It is worthy to note that, once again, the largest error refers to a local landmark, Ingresso Edificio, even when the stairs are in the walking direction; allocating it in the same position where it was learned (Fig. 7). This experiment confirms the perception that participants have of the different distant landmarks. With respect to the global landmarks the movement is recorded, but with reference to the local landmarks it is as if they do not move. The two reference systems are clearly distinct. Although this is not so evident for participants in the first group when the other local landmark, Cartina, is also included, Table 1 reports a higher frequency of errors in the positioning it (Fig. 8).

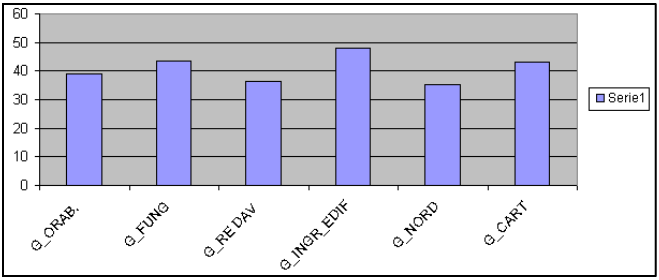


Figure 8 - Mean error in the accuracy pointing to the participants of the 1st group

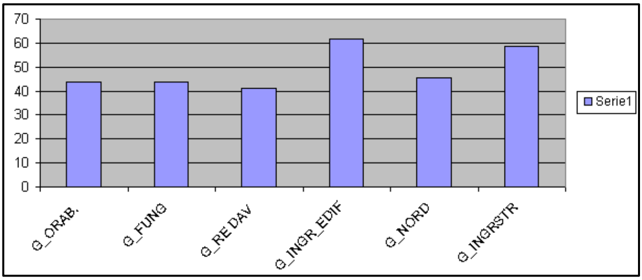


Figure 9 - Mean error in the accuracy pointing to the participants of the 2nd group

Most evident is for the participants in the second group, where the other local landmark, Ingresso Strutture, is the one that shows highest mean error along with Ingresso Edificio. From the observation of the data, it is noted that local landmarks (Ingresso Edificio and Cartina) exhibit a particular behavior, presenting a higher mean error compared to other landmarks, when the stairs involve a turn, and less pronounced for participants in the first group with a direct approach to the stairs. Specifically, they are allocated in the same position where they were learned, as if there had been no movement within the building or if the frames of references adopted for local and global landmarks were different. In other words, movements within the building are not perceived probably due to a difference in scale; global landmarks are distant and therefore rotated in the cognitive map, while local ones are perceived as too close. Evidently, the underlying logics are different and lead to hypothesizing a difficulty in integrating scales of different granularity or the adoption of a different frame of reference. There are no particular behaviors observed for the North. In the literature (Montello, 1991; Steck and Mallot, 2000; Credé, 2019; Credé 2020), it is reported that it is difficult to unequivocally define whether local landmarks are more significant than global ones or cardinal directions, or vice versa. Many residents move with skill in familiar environments often without knowing the cardinal directions, or the use of cardinal directions could result from learning the environment through maps, which define an *orientation-dependent* knowledge.

The model seems to satisfy the starting hypotheses and support the hypothesis that two SFRs are distinct.

Instead, systematic errors attributable to confusion between the body's symmetry axes seem to be very frequent, such as Back-Right (BR), Back-Left (BL), Front-Right (FR), Front-

Back (FB), or F-B confusions, especially for local landmarks. This is particularly interesting because it could provide an explanation for the different behaviors for landmarks. It is possible that for global landmarks, participants adopt an *Object-to-Object* reference, reconstructing spatial relationships between them without referring to their own body, imagining a configuration from a bird's-eye perspective of the environment (Easton and Sholl, 1995; Xiao and Zhang, 2013). Moreover, the required prerequisite is the knowledge of the Campus area. In this sense, it is even probable that participants build a map, adopting a reference landmark, and then, as they perform the pointing task, once the first one is positioned, allocate the others relative to this with reference to the map built during the learning phase. In such a scheme, it becomes difficult to allocate the closest landmarks, which are positioned as if there had been no movement within the building, hence in the initial position. For local ones, therefore, they might rely more on a *Self-to-Object* reference; and not knowing the building, of which they do not have a configurational knowledge, the allocentric system associated with it and the egocentric one specific to the subject come into conflict.

The trend of latencies does not show any interesting differences; rather not showing any particular trend could indicate a difficulty in reconstructing spatial relationships.

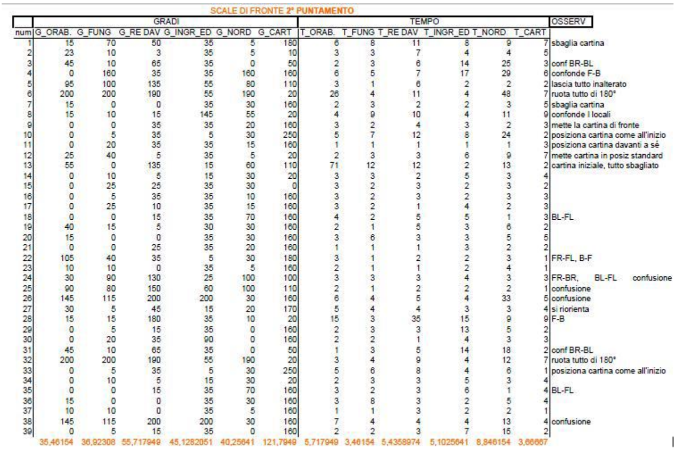
Ultimately, although the 90° turn before accessing the stairs did not result in an average error of 90°, it should be noted, looking at the observations in Table 1, that, if purified from the data of subjects manifesting better skills and not committing major errors, the others seem to be affected precisely by this effect.

The data at the second observation point is now analyzed, specifically when both groups, in both cases, exit the stairwell, walk thought the atrium (common to all floors), and then make a left turn. The absolute values of errors in the two approaches were compared using a one-way ANOVA analysis on the degrees and direction of approach to the stairs (front, side). The result for the second pointing provides a value of $p = 0.488 > 0.05$, which is not statistically significant, indicating that there is no substantial difference between the groups. Regarding latencies, the one-way ANOVA on the reaction time and the approach direction provided a value of $p = 0.000$.

Table 2 reports errors in terms of angular deviations taken in absolute value, with respect to the correct position of the landmarks. Were tolerated errors of 5°.

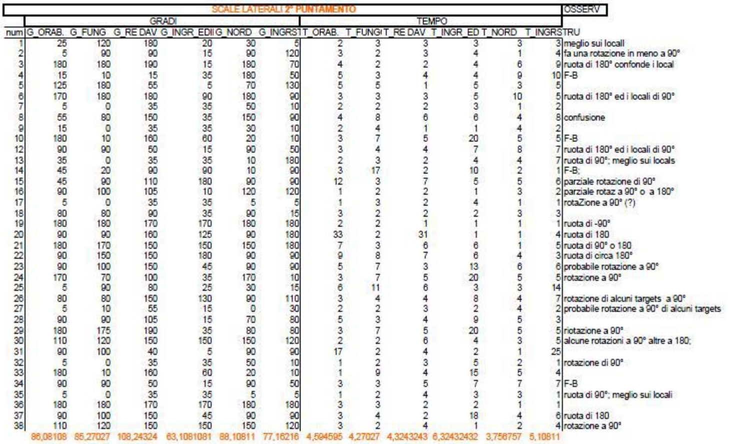
From the data in Fig. 10, it is possible to notice that participants in the second group make a greater mistake, which, although not 90°, is about 50°. Somehow, those who face the stairs making a turn perceive a rotation on their path but fail to properly integrate it. Participants in the second group, as expected, make more errors, probably, upon exiting the stairwell, they recognized the environment and relied more on it than on their memory, thus neglecting the position of the stairs relative to their path. Somehow, by recognizing the environment, they nullified the memory of the rotation performed. Fig. 10 shows a comparison of accuracies and latencies in the fourth pointing.

Front and Left-Front are more accurate than Right-Back and Left-Back. Still, with considerable frequency, there is a confusion between the axes on one's own body and confusing the directions Front-Right (FR) Front-Back (FB) and Back-Left (BL) Front-Left (FL), Front- Back (F-B). For this reason pointings are made with the exact angles but in the wrong directions. This is also a finding in the literature; Kozhevnikov et al. (2006) attribute it to the adoption of an egocentric SFR. Mental rotations, indeed, induce errors different from these and more related to underestimations or overestimations of the rotation angles.



SCALE DI FRONTE 2° PUNTAMENTO

	GRADI						TEMPO						OSSERV
num	G_ORAB.	G_FUNG	G_RE DAV	G_INGR_ED	G_NORD	G_CART	T_ORAB.	T_FUNG	T_RE DAV	T_INGR_ED	T_NORD	T_CART	
1	15	70	50	35	5	180	6	8	11	8	9	7	sbaglia cartina
2	23	10	3	35	5	10	3	3	7	4	4	5	
3	45	10	65	35	0	50	2	3	6	14	25	3	conf BR-BL
4	0	160	35	35	160	160	6	5	7	17	29	6	confonde F-B
5	95	100	135	55	80	110	3	1	6	2	2	2	lascia tutto inalterato
6	200	200	190	55	190	20	26	4	11	4	48	7	ruota tutto di 180°
7	15	0	0	35	30	160	2	3	2	2	3	5	sbaglia cartina
8	15	10	15	145	55	20	4	9	10	4	11	9	confonde I locali
9	0	0	35	35	20	160	3	2	4	3	2	3	mette la cartina di fronte
10	0	5	35	5	30	250	5	7	12	8	24	2	posiziona cartina come all'inizio
11	0	20	35	35	15	160	1	1	1	1	1	3	posiziona cartina davanti a sé
12	25	40	5	35	5	20	2	3	3	6	9	7	mette cartina in posiz standard
13	55	0	135	15	60	110	71	12	12	2	13	2	cartina iniziale, tutto sbagliato
14	0	10	5	15	30	20	3	3	2	5	3	4	
15	0	25	25	35	30	0	3	2	3	2	3	2	
16	0	5	35	35	10	160	3	2	3	2	3	3	
17	0	25	10	35	15	160	3	2	1	4	2	3	
18	0	0	15	35	70	160	4	2	5	5	1	3	BL-FL
19	40	15	5	30	30	160	2	1	5	3	6	2	
20	15	0	0	35	30	160	3	6	3	3	5	5	
21	0	0	25	35	20	160	1	1	1	3	2	2	
22	105	40	35	5	30	180	3	1	2	2	3	1	FR-FL, B-F
23	10	10	0	35	5	160	2	1	1	2	4	1	
24	30	90	130	25	100	100	3	3	3	4	3	3	FR-BR, BL-FL confusione
25	90	80	150	60	100	110	2	1	2	2	2	1	confusione
26	145	115	200	200	30	160	6	4	5	4	33	5	confusione
27	30	5	45	15	20	170	5	4	4	3	3	4	si riorienta
28	15	15	180	35	10	20	15	3	35	15	9	9	F-B
29	0	5	15	35	0	160	2	3	3	13	5	2	
30	0	20	35	90	0	160	2	2	1	4	3	3	
31	45	10	65	35	0	50	1	3	5	14	18	2	conf BR-BL
32	200	200	190	55	190	20	3	4	9	4	12	7	ruota tutto di 180°
33	0	5	35	5	30	250	5	6	8	4	6	1	posiziona cartina come all'inizio
34	0	10	5	15	30	20	2	3	3	5	3	4	
35	0	0	15	35	70	160	3	2	3	6	1	4	BL-FL
36	15	0	0	35	30	160	3	8	3	2	5	4	
37	10	10	0	35	5	160	1	1	3	2	2	1	
38	145	115	200	200	30	160	7	4	4	4	13	4	confusione
39	0	5	15	35	0	160	2	2	3	7	15	2	
	35,46154	36,92308	55,717949	45,1282051	40,25641	121,7949	5,717949	3,46154	5,4358974	5,1025641	8,846154	3,66667	



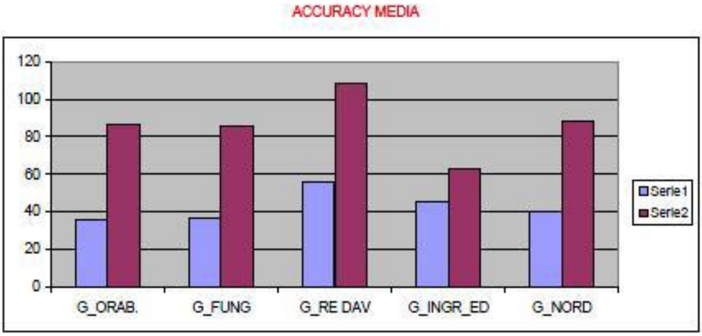
SCALE LATERALI 2° PUNTAMENTO

	GRADI						TEMPO						OSSERV
num	G_ORAB.	G_FUNG	G_RE DAV	G_INGR_EDI	G_NORD	G_INGRST	T_ORAB.	T_FUNG	T_RE DAV	T_INGR_ED	T_NORD	T_INGRS	TRU
1	25	120	180	20	30	5	2	3	3	3	3	3	meglio sui locall
2	5	90	90	15	90	120	3	2	3	4	1	4	fa una rotazione in meno a 90°
3	180	180	190	15	180	70	4	2	2	4	6	9	ruota di 180° confonde i local
4	15	10	15	35	180	50	5	3	4	4	9	10	F-B
5	125	180	55	5	70	130	5	5	1	5	3	5	
6	170	180	180	90	180	90	3	3	3	5	10	5	ruota di 180° ed i locali di 90°
7	5	0	35	35	50	10	2	2	2	3	1	2	
8	55	80	150	35	150	90	4	8	6	6	4	8	confusione
9	15	0	35	35	30	10	2	4	1	1	4	2	
10	180	10	160	60	20	10	3	7	5	20	5	5	F-B
12	90	90	50	15	90	50	3	4	4	7	8	7	ruota di 180° ed i locali di 90°
13	35	0	35	35	10	180	2	3	2	4	4	7	ruota di 90°; meglio sui locals
14	45	20	90	90	10	90	3	17	2	10	2	1	F-B;
15	45	90	110	180	90	90	12	3	7	5	5	6	parziale rotazione di 90°
16	90	100	105	10	120	120	1	2	2	1	3	2	parziale rotaz a 90° o a 180°
17	5	0	35	35	5	5	1	3	2	4	1	1	rotaZione a 90° (?)
18	80	80	90	35	90	15	3	2	2	2	3	3	
19	180	180	170	170	180	180	2	2	1	1	1	1	ruota di -90°
20	90	90	160	125	90	180	33	2	31	1	1	4	ruota di 180
21	180	170	150	150	150	180	7	3	6	6	1	5	ruota di 90° o 180
22	90	150	150	180	90	90	9	8	7	6	4	3	ruota di circa 180°
23	90	100	150	45	90	90	5	7	3	13	6	6	probabile rotazione a 90°
24	170	70	100	35	170	10	3	7	5	20	5	5	rotazione a 90°
25	5	90	80	25	30	15	6	11	6	3	3	14	
26	80	80	150	130	90	110	3	4	4	8	4	7	rotazione di alcuni targets a 90°
27	5	10	55	15	0	30	2	2	3	2	4	2	probabile rotazione a 90° di alcuni targets
28	90	90	105	15	70	80	5	3	4	9	5	3	
29	180	175	190	35	80	80	3	7	5	20	5	5	riotazione a 90°
30	110	120	150	150	150	120	2	2	6	4	3	5	alcune rotazioni a 90° altre a 180;
31	90	100	40	5	90	90	17	2	4	2	1	25	
32	5	0	35	35	50	10	1	2	3	5	2	1	rotazione di 90°
33	180	10	160	60	20	10	1	9	4	15	5	4	
34	90	90	50	15	90	50	3	3	5	7	7	7	F-B
35	5	0	35	35	5	5	1	2	4	3	3	1	ruota di 90°; meglio sui locali
36	180	180	170	170	180	180	3	3	2	2	1	1	
37	90	100	150	45	90	90	3	4	2	18	4	6	ruota di 180
38	110	120	150	150	150	120	3	2	4	1	2	4	rotazione a 90°
	86,08108	85,27027	108,24324	63,1081081	88,10811	77,16216	4,594595	4,27027	4,3243243	6,32432432	3,756757	5,10811	

Table 2 - Comparison between mean errors, in absolute value, during the 2° pointing

Interestingly among the global landmarks, there are more errors for pointing at the entrance in Re David street. This could be attributed to the fact that in this position, such a landmark is situated behind. Kozhevnikov et al. (2006) citing Kozhevnikov & Hegarty (2001) report that responses in front are much more accurate than those behind, and Right-

Moreover, in this case, the placement of landmarks along standard directions 0°, 90°, 180°, 270° was frequent, probably following compensation heuristics: to simplify the cognitive load, there is a tendency to remember the direction by approximating it to axes that are easier to remember (Tversky, 1981).



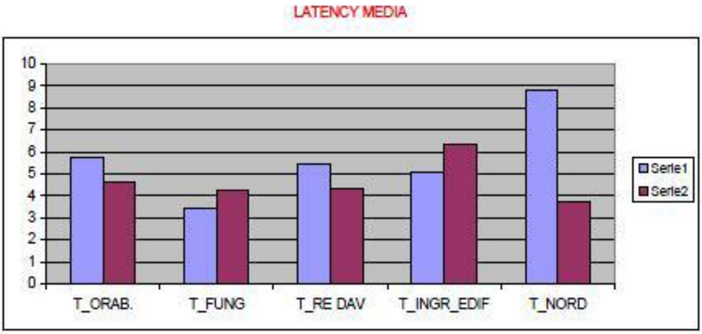


Figure 10 - Comparison between the mean errors in absolute value in the 2nd pointing of the accuracies and latencies.

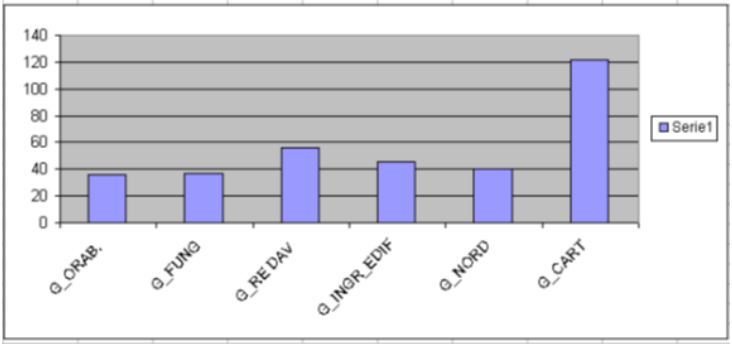


Figure 11 - Comparison between the mean errors in absolute value in the 2nd pointing for the accuracies for participants in the 1st group

In Fig. 11, a significant error is observed for pointing to Cartina, a local landmark for participants in the first group, consistent with the observations reported in Table 2. There is a tendency for participants to allocate Cartina in front of them as it was during the first pointing, effectively as if they had not moved relative to it.

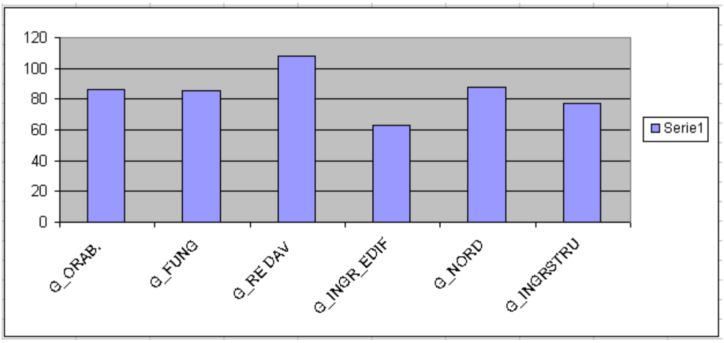


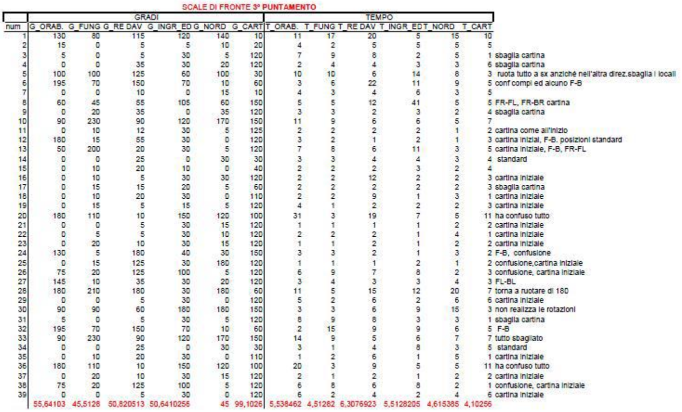
Figure 12 - Comparison between the mean errors in absolute value in the 2nd pointing for accuracies for the participants in the 2nd group

Moreover, in the final questionnaires, participants often report not being able to correctly position the local landmarks because they feel they are too close. This phenomenon is not found for participants in the second group, but with reference to the above, it should be noted that the local landmark, Ingresso Strutture, in this case, is positioned in front of the participant, so it might be easy to find it.

In conclusion, although the turn before approaching the stairs does not induce a perfect rotation of the landmarks of 90°, also in this case it has generated a greater disorientation, undermining the stability of the cognitive map. Once again, there are no particular difficulties in pointing North, although often indicated, in the questionnaires, as difficult to allocate as *non-physical*. The only data that confirms this statement is a greater latency at least for participants in the second group, a symptom of difficulty in allocating it even if correctly. The other latencies do not provide any particular information.

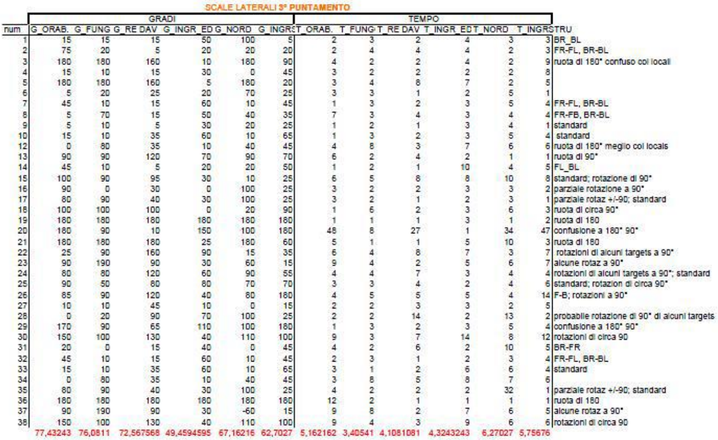
The third pointing is made following the corridor, which presents a right curve, thus ending up exactly in the initial learning direction. The absolute values of errors in the two approaches were compared using a one-way ANOVA analysis on the degrees and direction of approach to the stairs (front, side). The result for the third pointing provides a value of $p = 0.473 > 0.05$, which is not statistically significant, indicating that there is no substantial difference between the groups. Regarding latencies, the one-way ANOVA analysis on the reaction times and approach direction provided a value of $p = 0.017 < 0.05$.

In Table 3, errors in terms of angular deviations taken in absolute value are reported, relative to the correct position of the landmarks. Errors of 5° were tolerated.



SCALE DI FRONTE 3° PUNTAMENTO

	GRADI						TEMPO						
num	G_ORAB.	G_FUNG	G_RE DAV	G_INGR_ED	G_NORD	G_CART	T_ORAB.	T_FUNG	T_RE DAV	T_INGR_ED	T_NORD	T_CART	
1	130	80	115	120	140	10	11	17	20	5	15	10	
2	15	0	5	5	10	20	4	2	5	5	5	5	
3	5	0	5	30	5	120	7	9	8	2	5	1	sbaglia cartina
4	0	0	35	30	20	120	2	4	4	3	3	6	sbaglia cartina
5	100	100	125	60	100	30	10	10	6	14	8	3	ruota tutto a sx anziché nell'altra direz.sbaglia i locali
6	195	70	150	70	10	60	3	6	22	11	9	5	conf compl ed alcuno F-B
7	0	0	10	0	15	10	4	3	4	6	3	5	
8	60	45	55	105	60	150	5	5	12	41	5	5	FR-FL, FR-BR cartina
9	0	20	35	0	35	120	3	3	2	3	2	4	sbaglia cartina
10	90	230	90	120	170	150	11	9	6	6	5	7	
11	0	10	12	30	5	125	2	2	2	2	1	2	cartina come all'inizio
12	180	15	55	30	0	120	3	2	1	2	1	3	cartina inizial, F-B. posizioni standard
13	50	200	20	30	5	120	7	8	6	11	3	5	cartina iniziale, F-B, FR-FL
14	0	0	25	0	30	30	3	3	4	4	3	4	standard
15	0	10	20	10	0	40	2	2	2	3	2	4	
16	0	10	5	30	30	120	2	2	12	2	2	3	cartina iniziale
17	0	15	15	20	5	60	2	2	2	2	2	3	sbaglia cartina
18	0	10	20	30	0	110	2	2	9	1	3	1	cartina iniziale
19	0	15	5	15	5	120	4	1	2	2	2	3	cartina iniziale
20	180	110	10	150	120	100	31	3	19	7	5	11	ha confuso tutto
21	0	0	5	30	15	120	1	1	1	1	2	2	cartina iniziale
22	0	5	5	30	10	120	2	2	2	1	4	1	cartina iniziale
23	0	20	10	30	15	120	1	1	2	1	2	2	cartina iniziale
24	130	5	180	40	30	150	3	3	2	1	3	2	F-B, confusione
25	0	15	125	30	180	120	1	1	1	2	1	2	confusione,cartina iniziale
26	75	20	125	100	5	120	6	9	7	8	2	3	confusione, cartina iniziale
27	145	10	35	30	20	120	3	4	3	3	4	3	FL-BL
28	180	210	180	30	180	60	11	5	15	12	20	7	torna a ruotare di 180
29	0	0	5	30	0	120	5	2	6	2	6	6	cartina iniziale
30	90	90	60	180	180	150	3	3	6	9	15	3	non realizza le rotazioni
31	5	0	5	30	5	120	8	9	8	3	3	1	sbaglia cartina
32	195	70	150	70	10	60	2	15	9	9	6	5	F-B
33	90	230	90	120	170	150	14	9	5	6	7	7	tutto sbagliato
34	0	0	25	0	30	30	3	1	4	8	3	5	standard
35	0	10	20	30	0	110	1	2	6	1	5	1	cartina iniziale
36	180	110	10	150	120	100	20	3	9	5	5	11	ha confuso tutto
37	0	20	10	30	15	120	2	1	2	1	2	2	cartina iniziale
38	75	20	125	100	5	120	6	8	6	8	2	1	confusione, cartina iniziale
39	0	0	5	30	0	120	6	2	4	2	4	6	cartina iniziale
	55,64103	45,5128	50,820513	50,6410256	45	99,1026	5,538462	4,51282	6,3076923	5,5128205	4,615385	4,10256	

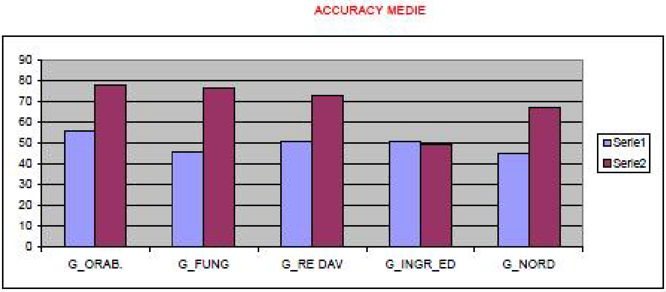


SCALE LATERALI 3° PUNTAMENTO

	GRADI						TEMPO						
num	G_ORAB.	G_FUNG	G_RE DAV	G_INGR_ED	G_NORD	G_INGRS	T_ORAB.	T_FUNG	T_RE DAV	T_INGR_ED	T_NORD	T_INGRS	TRU
1	15	15	15	50	100	5	2	3	2	4	3	3	BR_BL
2	75	20	5	20	20	20	2	4	4	4	2	3	FR-FL, BR-BL
3	180	180	160	10	180	90	4	2	2	4	2	9	ruota di 180° confuso coi locali
4	15	10	15	30	0	45	3	2	2	2	2	8	
5	180	180	160	5	180	20	3	4	8	7	2	5	
6	5	20	25	20	70	25	3	3	1	2	5	1	
7	45	10	15	60	10	45	1	3	2	3	5	4	FR-FL, BR-BL
8	5	70	15	50	40	35	7	3	4	3	4	4	FR-FB, BR-BL
9	5	10	5	30	20	25	1	2	1	3	4	1	standard
10	15	10	35	60	10	65	1	3	2	3	5	4	standard
12	0	80	35	10	40	45	4	8	3	7	6	6	ruota di 180° meglio coi locals
13	90	90	120	70	90	70	6	2	4	2	1	1	ruota di 90°
14	45	10	5	20	20	50	1	2	1	10	4	5	FL_BL
15	100	90	95	30	10	25	6	5	8	8	10	8	standard; rotazione di 90°
16	90	0	30	0	100	25	3	2	2	3	3	2	parziale rotazione a 90°
17	80	90	40	30	100	25	3	2	1	2	3	1	parziale rotaz +/-90; standard
18	100	100	100	0	20	90	1	6	2	3	6	3	ruota di circa 90°
19	180	180	180	180	180	180	1	1	1	3	1	2	ruota di 180
20	180	90	10	150	100	180	48	8	27	1	34	47	confusione a 180° 90°
21	180	180	180	25	180	60	5	1	1	5	10	3	ruota di 180
22	25	90	160	90	15	35	6	4	8	7	3	7	rotazioni di alcuni targets a 90°
23	90	190	90	30	60	15	9	4	2	5	6	7	alcune rotaz a 90°
24	80	80	120	60	90	55	4	4	7	3	4	4	rotazioni di alcuni targets a 90°; standard
25	90	50	80	80	70	70	3	3	4	2	4	6	standard; rotazion di circa 90°
26	85	90	120	40	80	180	4	5	5	5	4	14	F-B; rotazioni a 90°
27	10	10	45	10	0	15	2	2	3	3	2	5	
28	0	20	90	70	100	25	2	2	14	2	13	2	probabile rotazione di 90° di alcuni targets
29	170	90	65	110	100	180	1	3	2	3	5	4	confusione a 180° 90°
30	150	100	130	40	110	100	9	3	7	14	8	12	rotazioni di circa 90
31	20	0	15	40	0	45	4	2	6	2	10	5	BR-FR
32	45	10	15	60	10	45	2	3	1	2	3	4	FR-FL, BR-BL
33	15	10	35	60	10	65	3	1	2	6	6	4	standard
34	0	80	35	10	40	45	3	8	5	8	7	6	
35	80	90	40	30	100	25	4	2	2	2	32	1	parziale rotaz +/-90; standard
36	180	180	180	180	180	180	12	2	1	1	1	1	ruota di 180
37	90	190	90	30	-60	15	9	8	2	7	6	5	alcune rotaz a 90°
38	150	100	130	40	110	100	9	4	3	9	6	6	rotazioni di circa 90
	77,43243	76,0811	72,567568	49,4594595	67,16216	62,7027	5,162162	3,40541	4,1081081	4,3243243	6,27027	5,75676	

Table 3 - Comparison between mean errors, in absolute value, during the 3rd pointing

What interestingly emerges from the comparison between Fig. 13 related to the third pointing, Fig. 10 related to the second, and Fig. 7 related to the first is that the mean error has a rather peculiar trend. During the first pointing, it is significant for participants in both groups, although they face the learning direction. During the second pointing, a reduction in the mean error value is observed, at least for participants in the first group, as if crossing the atrium somehow contributes to stabilizing their map. However, the third pointing again sees an increase in error. This simply could be due to increased cognitive load. During locomotion, mammals in general, and humans activate a navigation process that allows integrations of rotations and translations to estimate the current position and define orientation within a wider environment.



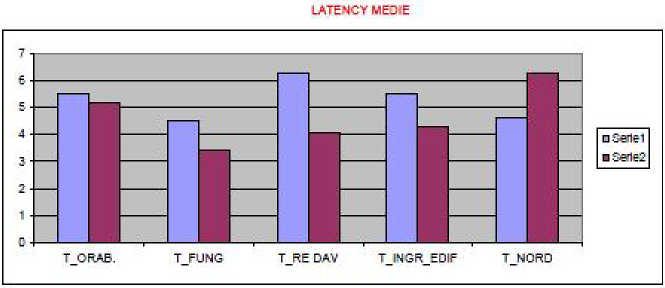


Figure 13 - Comparison between the mean errors in absolute value in the 3° pointing of the accuracies and latencies

This process, known as path integration, is possible thanks to information from our senses through vision or from our body through proprioception resulting from body movement (Kelly, 2009; Etienne and Jeffery, 2004; Philbeck and O'Leary, 2005; Kelly and McNamara, 2008; Kelly et al., 2008).

Vectors are constructed in relation to the initial position or encountered landmarks, which are then updated during the journey (Wang and Spelke, 2002). According to Kelly *et al.* (2008), in impoverished environments, *path integration* becomes fundamental as the absence of external reference points forces greater reliance on the flow of visual, proprioceptive, or kinesthetic information from one's own body. In fact, our path appears quite poor after passing the central atrium, which contributes to improving performance during the second task; it consists of two poorly illuminated corridors during the experiment, on both sides of which there are some doors without particular features. But what matters most is that the authors, citing the literature, argue that in updating task, such as path integration, the limits of human abilities emerge also in relation to the length of the route and especially the number of segments it comprises. The results of an experiment by Klatzky et al. (1990) are reported, where blind participants, traversing paths of varying lengths from one to three segments, simply separated by a turn, provided worse performance in the pointing task as the number of segments increased. In the absence of significant landmarks, spatial orientation significantly worsens with increasing information to be remembered. If the process of path integration is not carried out correctly, the decoding of self-to-object relations, namely relationships in the egocentric system, is affected, which could once again explain why the largest errors are made on local landmarks. As expected from the previous cases, this type of landmarks is probably integrated according to this reference.

It could be that the behavior of our participants responds to this model. In fact, in line with the observations reported in Table 3, a greater general confusion is observed, which manifests not only in reproducing the pattern by making greater reference to the main (standard) axes 0°, 90°, 180°, 270°, but also in making comparable errors, albeit higher for the second group. This is a demonstration that with the increasing complexity of the path there is a tendency to lose track of the translations and rotations made.

The tendency to confuse the axes of one's own body by reversing directions Front-Right (FR) Front-Back (FB) and Back-Left (BL) Front-Left (FL), Front-Back (F-B) remains, so that the pointing is done with exact angles but in the wrong direction.

Once again, although softened by calculating the mean error value, the observations in Table 3 report, for participants in the second group, a tendency to rotate the reconstruction of spatial relationships by 90° according to the rotation undertaken to approach the stairs.

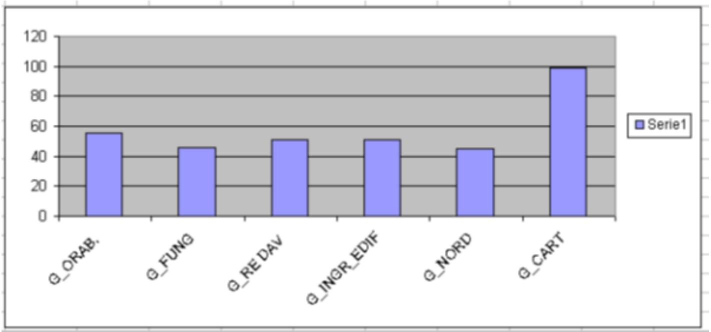


Figure 14 - Mean error accuracy in the 3°pointing task for the participants in the 1° group

As evident in Fig. 14, and consistent with the observations in Table 3, the error in pointing to the Cartina is systematic, which is always allocated in front, as it was during the first pointing. The error is greater compared to the other local landmark, Entrata Edificio, perhaps because the latter is positioned according to a predominant direction along the building perimeter. Indeed, it is known from the literature that the structure of the surrounding environment, the presence of boundary walls, or other strongly characterized elements from a geometric point of view, can define predominant intrinsic axes and reference directions simpler to remember (Mou and McNamara, 2002). Ultimately, all those characteristics that make some intrinsic organizations more salient than others help the reconstruction of spatial relationships. The map, however, does not occupy a prominent position within the building, thus reconstructing its position may be more complex.

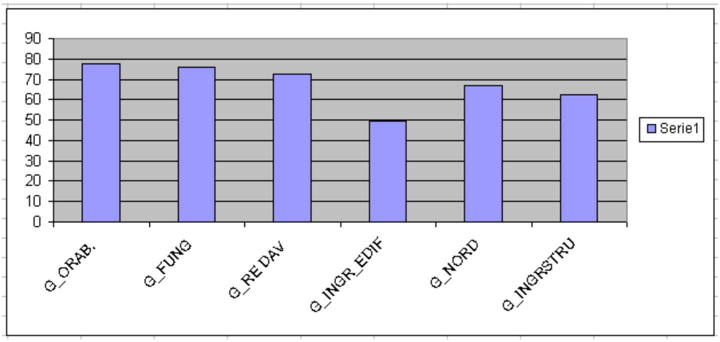


Figure 15 - Mean error accuracy in the 3rd pointing task for the participants in the 2nd group

This phenomenon could be confirmed in the results of participants in the second group, as the local landmark, Ingresso Strutture, is also positioned along a predominant direction of the building, and in any case, it is more distant

and could somehow have been integrated as global landmark.
No particular indication regarding mental rotation processes is provided by latencies.

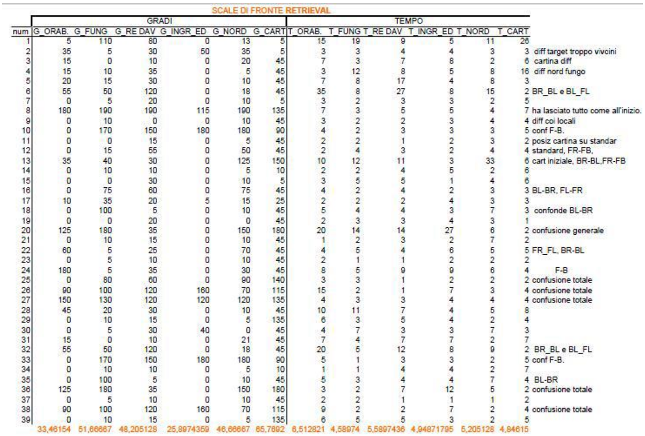
Retrieval

People are able to update relationships with objects even after imagining movements, not only after actually performing them. This task is generally more complicated, usually requiring longer times and affecting the accuracy of placements. However, it can be interesting to evaluate how they reconstruct their cognitive maps. For this purpose, participants, after completing navigation within the building, are taken to a windowless room and asked to imagine themselves standing with their backs to the elevator. Both groups face a position rotated 180° from the learning direction. Following the same criteria, the experimenter asks them to report on separate sheets the positions of the targets, which will be called randomly. Once again, accuracy and latency are evaluated and compared for the two groups. The absolute values of errors in the two approaches were compared using a one-way ANOVA analysis on the degrees and direction of approach to the stairs (front, side). The result for retrieval provides a value of $p = 0.001 < 0.05$, which, this time, is statistically significant, indicating that there is a substantial difference between the groups. To deepen the ANOVA analysis we used a Bonferroni post hoc test for multiple simultaneous comparisons between different landmarks within the same group. It allows to compare pairs of landmarks. The results provide $p = 0.714 > 0.05$ which indicates that the means are significantly different when compared. For the second group $p = 0.628 > 0.05$, therefore it can be interpreted in the same way.

To regard to the latencies the one-way ANOVA on the response time and the orientation of approach has provided $p = 0.145 > 0.05$.

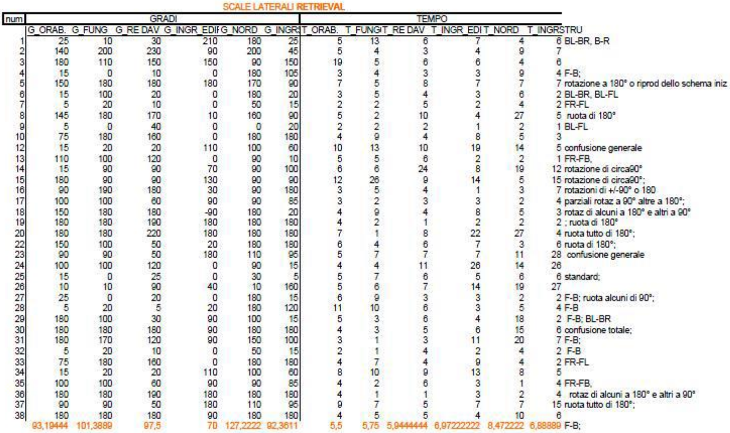
Since in this case, for both groups, the learning position and the one they have to imagine are the same, it is possible to compare the role played by the stairs in the construction of the cognitive map. If the stairs are well integrated, no conflict should arise. Table 4 shows some errors such as FR-FB, BR-BL, indicating, once again, that retrieval is also body-centered, meaning that in placing landmarks, participants refer to the coordinates of their body. Once again, there is a significant difference in error for the common local landmark, Ingresso Edificio, which is particularly low for participants in the first group and still lower than the other landmarks even for participants in the second group. However, this could be associated with the fact that this landmark was in front of them, on a perimeter wall that delimits the same stairwell, therefore easier to remember both because it is frontal and because it is along an intrinsic axis of the configuration. Again, participants in the second group tend to rotate the positions of the targets by 90° or even sometimes by 180°, as better shown in Fig. 16, evidently indicating that they have not integrated the position of the stairs rotated by the same angle relative to the learning position. This seems to confirm what was hypothesized.

It is interesting to note that the accuracy graphs have approximately the same trend and are phase-shifted by about 70°, which, considering the over/underestimations derived also from the tendency to place landmarks on the main axes, can approximate the 90° phase shift of the stairs. Also interesting is that here more than ever the pattern of the pilot experiment is reproduced, although in that case the approximation to 90° was even more pronounced, supporting the hypothesis that the underlying processes of finding spatial relations are the same.



SCALE DI FRONTE RETRIEVAL

	GRADI						TEMPO						
num	G_ORAB.	G_FUNG	G_RE DAV	G_INGR_ED	G_NORD	G_CART	T_ORAB.	T_FUNG	T_RE DAV	T_INGR_ED	T_NORD	T_CART	
1	5	110	80	0	13	5	15	19	9	5	11	26	
2	35	5	30	50	35	5	3	3	4	4	3	3	diff target troppo vivcini
3	15	0	10	0	20	45	7	3	7	8	2	6	cartina diff
4	15	10	35	0	5	45	3	12	8	5	8	16	diff nord fungo
5	20	15	30	0	10	45	7	8	17	4	8	3	
6	55	50	120	0	18	45	35	8	27	8	15	2	BR_BL e BL_FL
7	0	5	20	0	10	5	3	2	3	3	2	5	
8	180	190	190	115	190	135	7	3	5	5	4	7	ha lasciato tutto come all'inizio.
9	0	10	0	0	10	45	3	2	2	3	4	4	diff coi locali
10	0	170	150	180	180	90	4	2	3	3	3	5	conf F-B.
11	0	0	15	0	5	45	2	2	1	2	3	2	posiz cartina su standar
12	0	15	55	0	50	45	2	4	3	2	4	4	standard, FR-FB,
13	35	40	30	0	125	150	10	12	11	3	33	6	cart iniziale, BR-BL,FR-FB
14	0	10	10	0	5	10	2	2	4	5	2	6	
15	0	0	30	0	10	5	3	5	5	1	4	6	
16	0	75	60	0	75	45	4	2	4	2	3	3	BL-BR, FL-FR
17	10	35	20	5	15	25	2	2	2	4	3	3	
18	0	100	5	0	10	45	5	4	4	3	7	3	confonde BL-BR
19	0	0	20	0	0	45	2	3	3	4	3	1	
20	125	180	35	0	150	180	20	14	14	27	6	2	confusione generale
21	0	10	15	0	10	45	1	2	3	2	7	2	
22	60	5	25	0	70	45	4	5	4	6	5	5	FR_FL, BR-BL
23	0	5	10	0	10	45	2	1	1	2	2	2	
24	180	5	35	0	30	45	8	5	9	9	6	4	F-B
25	0	80	60	0	90	140	3	3	1	2	2	2	confusione totale
26	90	100	120	160	70	115	15	2	1	7	3	4	confusione totale
27	150	130	120	120	120	135	4	3	3	4	4	4	confusione totale
28	45	20	30	0	10	45	10	11	7	4	5	8	
29	0	10	15	0	5	135	6	3	5	4	2	4	
30	0	5	30	40	0	45	4	7	3	3	7	3	
31	15	0	10	0	21	45	7	4	7	7	2	7	
32	55	50	120	0	18	45	20	5	12	8	9	2	BR_BL e BL_FL
33	0	170	150	180	180	90	5	1	3	3	2	5	conf F-B.
34	0	10	10	0	5	10	1	1	4	4	2	7	
35	0	100	5	0	10	45	5	3	4	4	7	4	BL-BR
36	125	180	35	0	150	180	3	2	7	12	5	2	confusione totale
37	0	5	10	0	10	45	2	2	1	1	1	2	
38	90	100	120	160	70	115	9	2	2	7	2	4	confusione totale
39	0	10	15	0	5	135	6	5	5	3	2	5	
	33,46154	51,66667	48,205128	25,8974359	46,66667	65,7692	6,512821	4,58974	5,5897436	4,94871795	5,205128	4,84615	



SCALE LATERALI RETRIEVAL

num	GRADI						TEMPO						
	G_ORAB.	G_FUNG	G_RE DAV	G_INGR_EDI	G_NORD	G_INGR	T_ORAB.	T_FUNG	T_RE DAV	T_INGR_EDI	T_NORD	T_INGR	STRU
1	25	10	30	210	180	25	5	13	6	7	4	6	BL-BR, B-R
2	140	200	230	90	200	45	5	4	3	4	9	7	
3	180	110	150	150	90	150	19	5	6	6	4	6	
4	15	0	10	0	180	105	3	4	3	3	9	4	F-B;
5	150	180	180	180	170	90	7	5	8	7	7	7	rotazione a 180° o riprod dello schema iniz
6	15	100	20	0	180	20	3	5	4	3	6	2	BL-BR, BL-FL
7	5	20	10	0	50	15	2	2	5	2	4	2	FR-FL
8	145	180	170	10	160	90	5	2	10	4	27	5	ruota di 180°
9	5	0	40	0	0	20	2	2	2	1	2	1	BL-FL
10	75	180	160	0	180	180	4	9	4	8	5	3	
12	15	20	20	110	100	60	10	13	10	19	14	5	confusione generale
13	110	100	120	0	90	10	5	5	6	2	2	1	FR-FB,
14	15	90	90	70	90	100	6	6	24	8	19	12	rotazione di circa90°
15	180	90	90	130	90	90	12	26	9	14	5	15	rotazione di circa90°;
16	90	190	180	30	90	180	3	5	4	1	3	7	rotazioni di +/-90° o 180
17	100	100	60	90	90	85	3	2	3	3	2	4	parziali rotaz a 90° altre a 180°;
18	150	180	180	-90	180	20	4	9	4	8	5	3	rotaz di alcuni a 180° e altri a 90°
19	180	180	190	180	180	180	4	2	1	2	2	2	; ruota di 180°
20	180	180	220	180	180	180	7	1	8	22	27	4	ruota tutto di 180°;
22	150	100	50	20	180	180	6	4	6	7	3	6	ruota di 180°;
23	90	90	50	180	110	95	5	7	7	7	11	28	confusione generale
24	100	100	120	0	90	15	4	4	11	26	14	26	
25	15	0	25	0	30	5	5	7	6	5	6	6	standard;
26	10	10	90	40	10	160	5	6	7	14	19	27	
27	25	0	20	0	180	15	6	9	3	3	2	2	F-B; ruota alcuni di 90°;
28	5	20	5	20	180	120	11	10	6	3	5	4	F-B
29	180	100	30	90	100	15	5	3	6	4	18	2	F-B; BL-BR
30	180	180	180	90	180	180	4	3	5	6	15	6	confusione totale;
31	180	170	120	90	150	100	3	1	3	11	20	7	F-B;
32	5	20	10	0	50	15	2	1	4	2	4	2	F-B
33	75	180	160	0	180	180	4	7	4	9	4	2	FR-FL
34	15	20	20	110	100	60	8	10	9	13	8	5	
35	100	100	60	90	90	85	4	2	6	3	1	4	FR-FB,
36	180	180	190	180	180	180	4	1	1	3	2	4	rotaz di alcuni a 180° e altri a 90°
37	90	90	50	180	110	95	9	7	5	7	7	15	ruota tutto di 180°;
38	180	180	180	90	180	180	4	5	5	4	10	6	
	93,19444	101,3889	97,5	70	127,2222	92,3611	5,5	5,75	5,9444444	6,97222222	8,472222	6,88889	F-B;

Table 4 - Comparison between the mean errors, in absolute value during the retrieval

Although the profile of the latencies for the elements of the second group seems to increase with the magnitude of the rotation angle, which according to classical literature invokes processes of mental rotation (Shepard and Cooper, 1982), this is not found for the elements of the first group, thus not supporting this thesis, reflecting memory difficulties in inferring relative directions (Hintzman, 1981). Moreover, in literature, this model does not seem to adhere to cognitive maps, which could mean that in the retrieval phase, there is also an attempt to rotate the cognitive map. Once again, the Cartina turns out to be difficult to integrate into the cognitive map (Fig. 17).

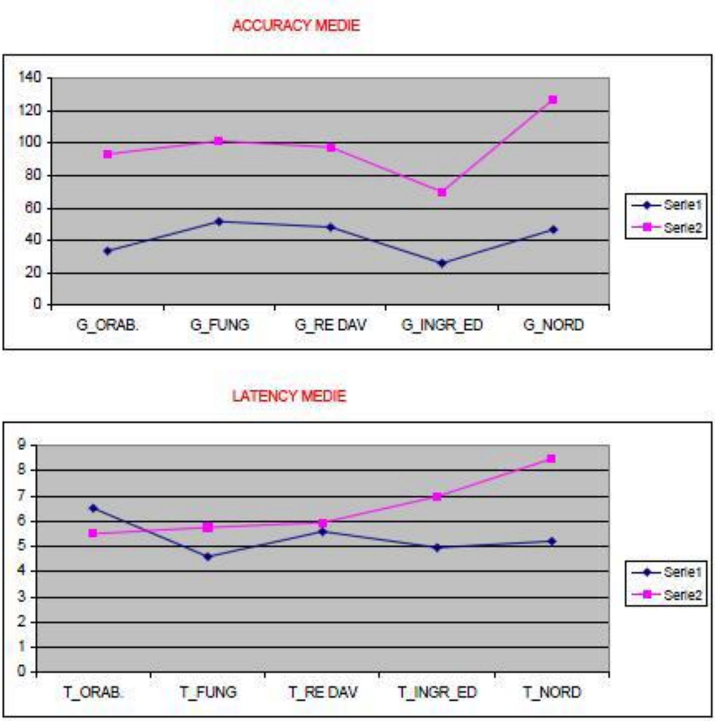


Figure 16 - Comparison between the accuracy mean error, in absolute value, during the retrieval. The same for latencies

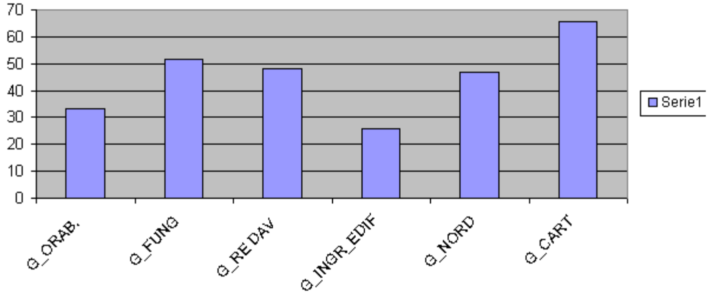


Figure 17 - Mean error in the accuracy during the retrieval for participants in the 1° group

The graph in Fig. 18 seems to confirm what has been stated so far, about the difference in integration of the two local landmarks.

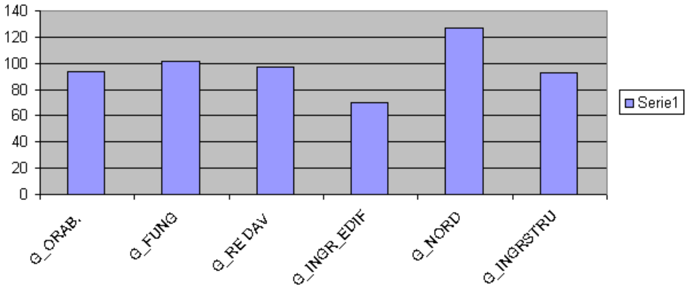


Figure 18 - Mean error in the accuracy during the retrieval for participants in the 2nd group

Discussion of Results

In this section, we discuss the results from the previous section concerning the behaviors of the participants moving in indoor environments characterized by the presence of stairs, which introduce rotational movements, and attempt to contextualize them within the theoretical framework referenced in the previous sections. It should be noted that the results of the pilot experiment are aligned with those presented here and seem to verify the initial hypothesis that the position of stairs, or rather their direction, has significant effects on people's orientation within multi-level buildings, and that local and global landmarks are integrated differently by human agents.

From the analysis conducted in the previous section, frequent and common errors in both experiments can be identified:

1. a tendency to allocate local landmarks in the original position without considering the movement relative to them;
2. pointing with a correct angle in the right direction while confusing the FR-FL, BR-BL, FR-BR, FL-BL axes;
3. a tendency to rotate the global landmarks according to the turn they make instead of in the opposite direction, nullifying the effect of the turn;
4. a tendency to allocate landmarks according to the directions of the main axes 0°, 90°, 180°, 270°.

In particular, when approaching the stairs involving a turn, participants:

- tend to allocate landmarks by placing them in the direction they learned them regardless for the rotation performed on the stairs, losing their bearings when still on the stairs;
- make more errors between right and left;
- have longer reaction times;
- often do not respect the relative positions of the landmarks, committing more errors;
- tend to reproduce the initial pattern when experiencing disorientation;

during retrieval, performances:

- improve significantly for local landmarks;
- tend to remember the first landmarks requested more accurately, as if the performance worsens with increasing cognitive load.

The results can be summarized as follows. Participants:

- adopt two different SFR between global and local landmarks;
- give importance to geometry;
- tend to maintain an egocentric SFR and to rotate landmarks (at least the global ones);
- reaction times are longer during retrieval to superimpose the global SFR on the local one;
- often ask to rotate their body or the sheet;
- tend to remember front landmarks better;
- construct a cognitive map with reference to global landmarks;
- during navigation, refer to an object-based representation by positioning landmarks with reference to each other;
- tend to rotate the map, making errors of over- or underestimation;
- when feeling disoriented, tend to resort to path integration, relying on egocentric spatial representations and confusing their body axes;
- assume that once at the top of the stairs, they are in the same direction as the learning phase (so if they made the turn, they make more errors);
- during retrieval, more often resort to self-to-object representations because they need to imagine themselves in a particular location;
- have more difficulty with local landmarks because they are perceived as too close;

- adopt a global landmark and then allocate all others with reference to this;
- mentally reproduce the path they walked.

In particular, it emerges that participants resort to egocentric transformations, thus relying on an egocentric SFR. This is consistent with the results of Kozhevnikov et al. (2006), for the significant number of errors made regarding their body axes and showing greater accuracy in pointing targets placed in front. Mental rotation transformations tend instead to produce errors of over or underestimation which, although present, have a lesser impact here. Specifically, responses in front are much more accurate than those backward, as reported in the analyses of the previous section.

This result is supported by other references in the literature: indeed, Rieser (1989) and Wang and Spelke (2000) argue that large-scale pointing direction tasks are *egocentric orientation*, so better performance during these tasks is probably due to accurate encoding of *self-to-object* relations and accurate path integration processes also based on egocentric representation systems. However, there is evidence that egocentric spatial transformations and rotations lead to different types of errors. Since the results of our experiments present, albeit with less frequency, errors of over or underestimation, it can be thought that participants consider global landmarks as an array, almost equidistant from them, and for these, they rely on *object-to-object* representation systems and refer to allocentric rotations. For local landmarks, they instead adopt *self-to-object* representation systems, overlaying the processes. This could justify the difference that is common to both experiments (Kozhevnikov et al., 2006). This phenomenon is even more evident when participants feel disoriented. In fact, in these cases, there is an attempt to reproduce the pattern exactly as learned in the learning phase.

In addition, as reported by Iachini and Logie (2003), a real environment learned through direct exploration could induce an orientation-dependent representation in memory, especially when the environment is unfamiliar, or only one perspective has been learned (Meilinger et al., 2006). In support, Presson and Montello (1994) argue that pointing tasks worsen when performed from imagined perspectives misaligned with the body because the frames of reference conflicts between two competing representations of the surrounding environment. Specifically, concerning rotation processes, these results suggest that spatial relations are encoded relative to Cartesian axes centered on one's body, as opposed to a polar system (Presson and Montello; 1994). An interesting phenomenon occurs during a 180° rotation, as in this case, participants rotate the map as a whole, almost without making errors. However, in literature, it is reported that such mirroring is a different process from mental rotation, although the mechanism responsible for this particular advantage has not yet been identified.

Another frequent occurrence is the tendency to better remember landmarks located along the principal axes or to allocate others along these standard positions. This aligns with the results of Montello and Sadalla's (1989) experiment on the ability to remember traversed angles. The authors find that when recalling spatial information, the least distorted angles are those at 0°, 90°, 180°, while errors increase when angles deviate from these coordinates. Memory tends to distort turns towards right angles in accordance with those proposed by Tversky (1981).

Furthermore, when making turns, it is more difficult to keep the body axes orthogonal aligned with the global references. This problem becomes more evident if it is erroneously assumed that the direction at the top of the stairs will be the same as the one from which we started; the conflict arises as inevitable (Montello, 1991).

The other emerged result was the tendency to better remember landmarks arranged along intrinsic axes of the configuration. According to Mou and McNamara (2002), both egocentric information and environmental features are used in the selection of preferential axes when one is unfamiliar with the environment. In this way, remembered and perceived environments coincide, allowing the route to be traced relative to the reference axis. According to Kelly and McNamara (2008), performance worsens when the geometrically uniform environment does not allow the definition of a reference axis, resulting in the accumulation of errors during path integration. The absence of strong environmental features maximizes the probability of relying on egocentric SFRs, as in our case.

Latencies reflect the accessibility of stored information. Referring to the retrieval process and the longer latencies required to reconstruct spatial relations, it should be noted that movement within multi-level buildings provides kinesthetic and proprioceptive information, suggesting the approximate direction, probably even the distances traveled, and allowing the update of the underlying spatial representation: this would make it easier to process conflicting perspectives. It is known from spatial updating results (Risier, 1989) that body rotation facilitates directional judgment compared to imagined rotation.

In the case of real motion, the cognitive resource consumption is minimal, the amount of spatial information to be processed is small, and therefore additional resources are available to process conflicting perspectives and alignment effects.

Regarding retrieval processes, while updating the positions of a limited number of objects may be relatively simple during physical movement, imagined movements lacking corresponding self-motion signals are more difficult (40).

In real environments, participants can study buildings, identify any peripheral landmarks, and these features could be used for orientation in addition to the information coming from the view of the building itself. Some of this information could have been available even though an attempt was made to keep the environment impoverished.

The rather irregular trends of the latencies indicate that landmarks were differently accessible, so it is unlikely that participants used mental rotation to reorient themselves in their cognitive maps. At most, they may have overlaid the mental rotation process with the environment scanning process in some cases.

Although the results seem to support the hypothesis that the direction of stairs plays a fundamental role in the disorientation of those navigating complex three-dimensional environments, there is no strong evidence that the mental map constructed during navigation can be rotated when spatial relations are recalled. More likely, participants simply mentally retrace the different segments of the path without regard for the rotations performed.

The constructed cognitive maps, therefore, are not rotated in accordance with what is reported in the literature.

Instead, it seems perfectly confirmed the hypothesis that individuals adopt different SFRs for the two types of landmarks, confirming that movements are perceived differently than them. It is very likely that different SFRs are adopted on different granularity of stairs. The results seem to confirm that participants mentally imagine themselves rotating or translating and continuously update the *self-to-object relations*, imagining their body moving in space relative to a stable object configuration, and access to the object's position occurs within egocentric coordinates after the process is completed (Easton and Sholl, 1995).

Our results suggest that individuals are particularly sensitive to disorientation after rotation, as indicated by the existence of a preferred environmental alignment and their inability to aim between planes after multiple turns. It is possible that integrating different levels is difficult or that people are unable to correctly update their position while crossing 90° turns on stairs as they are not perceived as rotations.

Participants probably represent the layout relative to the selected reference direction during learning and retain this configuration even after rotations, in accordance with the literature proposing that spatial memories are based on *orientation-dependent* representations. When misalignments occur, conflicts are triggered between SFRs according to Kelly et al. (2008).

The analysis of the questionnaires also concerned the adoption of mnemonic strategies. The subjects reported basically three tendencies: adoption of a reference landmark, reconstruction of a map with reference to this, and attempting to mentally trace the path. All are found in the results. However, the declared difficulty in pointing to the cardinal points is not found, although some participants stated that they had adopted them as a reference, if not in longer latencies. Many confirmed the difficulty of pointing to local landmarks, regarding which they could not orient themselves, in particular it is declaratively difficult to allocate the Cartina, as emerged from the analysis of the results. Some confirmed adopting a reference landmark, others recalling the initial scheme. Participants openly reported feeling disoriented along the stairs, and this is a very important fact as they had not been informed that the study aimed to evaluate the impact of stairs in general, and their position in particular, on the perception of environments.

Many during the experiment asked to move, especially to rotate or to be able to rotate the sheet. This was not allowed, however, it finds confirmation in the literature: Tversky in her *work On Abstraction and Ambiguity* (2015) reports that rotating the body facilitates mental updating and spatial orientation. She points out the importance of external actions to support mental operations and to internalize information, to establish a link between thinking and action and mental and physical transformations.

Some participants reported that the experiment was not difficult, but this is not always supported by their performances. This result indicates that very often they have no awareness of their own abilities; many, on the other hand, stated that they discovered on this occasion that they were not good navigators, contrary to what they assumed. Once again, the test was perceived as more difficult for participants in the second group, confirming that orthogonally arranged stairs imply greater cognitive effort in reconstructing spatial relations (Mastrodonato et al., 2013).

In sum, although performance is better when encountering stairs directly without having to make any turns, there is always a greater difficulty in pointing to local landmarks. This suggests that they are allocated in two different frames of reference. Space users likely organize the latter according to a hierarchy of spatial relationships, which are not easy to interchange. Specifically, it is probable that when allocating global landmarks, agents refer to a survey knowledge that can probably be placed at a higher level than simple landmark knowledge. Moreover, considering the considerable distances involved, it is likely that in comparison to movements made in smaller buildings, they are all perceived at the same distance as a regular array, easier to remember once one of the landmarks has been allocated in their cognitive map. On the other hand, when referring to local landmarks, agents likely refer to their egocentric experience of the navigated space, and the use of self-to-object relationships is complicated by the presence of rotational movements. In fact, it is as if, compared to the greater distances defined by global landmarks, the distances within the building are not integrated but continue to refer to the larger granularity: therefore, local landmarks tend to be positioned in the same place as they were in the learning phase. Their localization seems to be slightly better when they are located at prominent axes of space, such as perimeter walls. This seems to demonstrate quite clearly the adoption of references strongly anchored to the objective characteristics of the environment. Also frequent is the tendency to allocate landmarks along main directions 90°, 180°, or front/back, right/left according to the heuristics predicted by Tversky (2015) or *Kantian simplification* (Hillier, 2006), meaning the attempt to attribute a greater order and geometry to things in order to remember them more easily.

Conclusion

Whenever we are called upon to navigate in space, memory and perception act together because the world presents itself to the individual in its objectivity, but filtered through their perceptions, experiences, and skills (Tversky, 2005). Thus, when planning a route or simply giving directions, we often rely on memories acquired and stored in cognitive maps. In this work, we have tried to understand how these problems are addressed and resolved, and more specifically, which frames of reference are used to locate elements in space and the relationships that are built between objects and between oneself and the objects present in the surrounding environment. We have verified that these problems depend partly on cognitive load, the number of segments and turns encountered along the path, and the presence of features or landmarks that characterize space at a local or global level. Understanding how people live and interact with the built environment is a fundamental part of design choices today; this understanding can be obtained through careful observations and monitoring of behaviors. This work shows that the adoption of particular solutions can strongly influence the perception and experience of users (Schultz et al., 2013) and, consequently, designing the layout of an environment becomes a complicated and delicate operation because it influences the ease and integration of the same into the cognitive map; structures and readability influence the strategies employed to move within it. During the design phase, then, the difficulties that may be encountered in completing wayfinding tasks within the building must be taken into account. Unable to operate on subjective skills, to simplify navigation, a series of measures can be adopted concerning the environment, such as reducing the complexity of the layout. This work has paid particular attention to this last aspect; in fact, the results seem to show that the geometry of the environment is decisive in terms of performance. It emerged that the results of pointing tasks are better in the Bari experiment, where the layout is much simpler from a geometric point of view since it repeats exactly on all floors, compared to the pilot study where it changed from floor to floor. These evaluations could be appropriately implemented in design support systems for architects, designers, and planners.

In view of the advantages of the method used, the work presents several limitations; it is obvious that within an environment there are countless aspects that play a fundamental role: attractors, areas of visibility, layout complexity, qualitative elements, lights, and so on; it is impossible to analyze all the variables involved in orientation and navigation or to precisely isolate them to investigate them. We have limited ourselves to considering the effect of rotation induced by the presence of stairs without any regard for other elements. These interactions should be investigated. However, the data were collected in a real environment, on a large scale, avoiding reliance on memory. Maps were deliberately not used to avoid alignment effects or participants acquiring a configurational knowledge of the environment that would influence their reconstructions of spatial relationships. On the other hand, in a situation like this, it is impossible to analyze all the variables involved in orientation and navigation or to precisely isolate them to investigate them. Moreover, to this method is associated, albeit to a limited extent, a certain inaccuracy of the experimenter in collecting data, as this collection is done manually and is entrusted to their judgment, which inevitably is subjective. In any case, for the purposes of this work, an extremely refined observation was not necessary. Another problem is the one known in literature (Conroy, 2001) as the *experimenter effect*, namely that participants can be influenced by their presence or by the manner in which questions were asked.

The work was conducted with the aim of assisting in predicting elements that contribute to making the built environment more easily navigable in order to make it conveniently and easily usable, with the intent of understanding how it is used by people if its configuration or the arrangement of some of its elements changes. The results aim to provide designers with decision support systems in the design and planning phases.

More generally, this work aims at developing greater awareness of the problem of orientation in a public indoor space. However, that is a space characterized by multiple and differentiated uses, normally allowing navigation guided by diversified interests and objectives. Clearly the experimentation is artfully constructed and aimed at gathering knowledge on the orientation abilities and approaches of the agents involved. Yet the different types of spaces in that building have guaranteed the carrying out of those differentiated activities of agents - which is not always possible, as occurring e.g. in the case of a monofunctional building or with little assortment of functions, such as a residential house. It is also evident that the experimentation could not rely on more unstructured spatial elements in the building up of cognitive maps by the agents. This would have been the case for example of open spaces, where the structuring of the space navigated by the agents is extremely low if not absent. This would have generated a whole series of additional and different problems relating to orientation, as highlighted in some pilot works (Mastrodonato and Camarda, 2020). The present case study allows reasoning on spatial navigation and orientation as essential characteristics for the perception of spaces and their representation. Within spatial planning activities, which often involve large and very differently structured if not unstructured spaces, it is evident that the problem of orientation can take on very different characters. However, the results developed from our experimentation suggest that there are essential aspects of space perception that are able of characterizing possible uses of the space itself. Think for example of the studies carried out on the usability of public parks, in the search for the most suitable places and corners for the location of functional elements, tourist attractions, commercial activities, service equipment, etc. (Sugimoto, Koun, 2013; Schertz, 2018). Up to more general examples in which spatial planning addresses the regeneration of degraded areas, brownfields, polluted areas with the presence of stigma. In them the perception of navigability, of the usability of space by agents becomes essential for the regeneration activity itself and its effectiveness (Tendero and Bazart, 2024). Another increasingly addressed example is the role of spatial cognition, and in particular orientation, concerning spaces crossed by, and/or subject to, disastrous natural events - for example earthquakes in urban areas. In these problematic cases dealing with danger, risk management, evacuation, it is clear that issues of perception, orientation, and cognitive representation of space play a critical role. The planning and organization of spaces that are more fragile and more sensitive to these problems critically benefit from the knowledge of cognitive aspects (Santoro et al., 2022; Keykhaei et al., 2024). Orientation in particular contributes to address the complex aspects of urban planning for the regeneration of historic centers built in areas with strong seismicity (Mastrodonato et al., 2022).

In the near future our research group will try to develop experiences and reasoning on orientation, evolving research towards models to support the management of complex knowledge. In this context, the transition towards, and integration with, outdoor and/or open spaces will be explored in greater detail, with different degrees of space confinement or structuring and at medium/large scales. The objective will be to keep on contributing to the generation of systems that support complex decisions and planning in the typical contexts of spatial organization.

Author Contributions:

The paper is the result of a joint research work carried out by authors together and coordinated by D.C. Nonetheless, D.C. and G.M. wrote “Introduction” and “Discussion of Results” sections, whereas G.M. wrote other sections. Authors have read and agreed to the published version of the manuscript.

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