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# SPATIAL REPRESENTATION OF DESCRIBED ENVIRONMENTS: THE CHARACTERISTICS OF VERBAL DESCRIPTIONS AND THE ROLE OF PHYSICAL MOVEMENT

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# Table of Contents


**Introduction** 5

**PART I: VERBAL DESCRIPTIONS OF ENVIRONMENTS** 8

**1. Theories of language comprehension** 9

**1.1.** Mental Model Theory by Johnson-Laird 9

**1.2.** Other alternative theories for spatial text comprehension 10

**1.2.1.** The Theory of Van Dijk and Kintsch 10

**1.2.2.** Theory of Dual Coding of Paivio 11

**2. Spatial descriptions** 12

**2.1.** The role of spatial descriptions in promoting an adequate spatial representation 12

**2.2.** The functional equivalence hypothesis 14

**2.2.1.** Supportive findings 14

**2.2.2.** Controversial studies 15

**2.3.** Characteristics of the spatial descriptions: Focus on perspective 17

**2.3.1.** The influence of text perspective on spatial representation 17

**2.3.2.** The influence of past experience on spatial perspective preference 19

**2.4.** Working memory in spatial texts and the influence of text perspective 20

**2.4.1.** Dissociation between verbal and visuospatial Working Memory subcomponents 21

**2.4.2.** Working Memory subcomponents for spatial descriptions 21

**2.4.3.** The involvement of Working Memory subcomponents on spatial perspectives 23

**2.5.** Different types of spatial descriptions: previous evidence 26

**3. Experiment 1. Spatial descriptions and the serial position effect** 27

**3.1.** Introduction 27

**3.2.** Method 29

**3.3.** Data Analysis and Results 32

**3.4.** Discussion 33

**4. Experiment 2. The influence of encoding direction on retrieval of spatial information** 37

**4.1.** Introduction 37

**4.2.** Method 39

**4.3.** Data Analysis and Results 42

**4.4.** Discussion 43

**PART II: THE ROLE OF MOVEMENT IN SPATIAL COGNITION AND LEARNING** 46

**5. The components of physical movement and their contributions** 47

**5.1**. Taxonomy of body-based information 47

**5.2**. Different contributions from different cues 48

**5.2.1**. Visual-based and body-based information 48

**5.2.2**. Contribution from different sources of body-based information 50

**5.3**. A clarification for rotational and translational information 52

**6. The importance of physical movement in spatial tasks** 53

**6.1.** Individual mobility skills 53

**6.2.** The spatial updating 54

**6.2.1.** Spatial updating after body motion: rotation and translation 55

**6.2.2.** Spatial updating for remote environments 55

**6.2.3**. Representational systems of spatial memory and updating 57

**6.3.** Alignment effects: encoding and sensorimotor 59

**7. The role of physical movement in described environments** 61

**7.1.** Action-grounded language: linguistic meaning approaches 61

**7.2.** Action-grounded language: empirical evidence 62

**8. The role of physical movement in narratives** 64

**8.1.** The influence of the encoding perspective 64

**8.2.** Physical movement and narratives 65

**9. Experiment 3. The influence of walking on spatial updating of described environments** 69

**9.1.** Introduction 69

**9.2.** Method 72

**9.3.** Data analysis and Results 77

**9.4.** Discussion 81

**10. Experiment 4. The influence of walking during the encoding of described environments** 85

**10.1**. Introduction 85

**10.2.** Method 88

**10.3.** Data Analysis and Results 91

**10.4.** Discussion 93

**11. Experiment 5. The influence of encoding modalities on spatial navigation** 97

**11.1.** Introduction 97

**11.2.** Method 99

**11.3.** Data Analysis and Results 101

**11.4.** Discussion 102

**12. Conclusions** 105

**12.1.** General discussion 105

**12.2.** Theoretical perspectives 106

**12.3.** Applied perspectives 109

**References** 112

# Introduction

Verbal descriptions of an environment are commonly used in daily life to communicate spatial information, such as the position of relevant landmarks and their relations. It has been demonstrated that the verbal description of an environment allows the creation of a mental representation of the environment that is functionally equivalent to that derived from direct perception. Therefore, it seems that the verbal description of an environment is effective in providing spatial information about environments that are not directly perceived. In this framework physical movements seem to play an important role in enhancing people's ability to successfully interact with the described environments. Thus, the aim of the present work is to shed light on the role of physical movements in supporting verbal descriptions in the construction of effective spatial representations, which should be able to help people to act in the described environments.

The present work is structured in two main parts, consistent with the two key factors which seem to guide the construction of spatial representations in described environments – that is, spatial descriptions and physical movements. The first part of the thesis (Chapters 1–4) deals with the specific characteristics of verbal descriptions which could affect the corresponding mental representations, reviewing the most relevant evidence related to spatial text comprehension. However, the first part should be considered a necessary introduction for the theoretical core of the present work, which will be illustrated in the second part. Therefore, the second part (Chapters 5–11) deals with the influence of physical movement on spatial updating and navigation in described environments, presenting theoretical approaches and empirical evidence related to the role played by physical movements on spatial cognition.

In Chapter 1, the most relevant theories of language comprehension will be discussed in order to provide a theoretical framework for the empirical evidence subsequently presented. Thus, the Theory of Mental Models by Johnson-Laird will be extensively described, focusing on the concept of mental models. This theory will be compared to some alternative theories – i.e., the Theory of Van Dijk and Kintsch and the Dual Coding Theory by Paivio – regarding text comprehension and role of imagery in a text.

Chapter 2 specifically focuses on the verbal description of an environment, that is a verbal text which conveys spatial information. Thus, in this chapter the contribution of spatial descriptions on the construction of adequate spatial representations will be widely reviewed, presenting both well–established and still controversial empirical findings in this domain. Then, the principle of functional equivalence of perceived and described environments will be explained. Moreover, this chapter will also deal with perspective, a particular characteristic of spatial descriptions which influence the construction of spatial representations as a function of previous visual experience. Finally, a brief discussion about the role of working memory in the encoding of spatial descriptions will be provided.

In Chapter 3, Experiment 1 will be reported. This experiment deals with the serial position effect of items (concrete objects) described in three different contexts: a classic word list, a spatial description of a room and a narrative without spatial information. We wanted to examine whether the spatial representation elicited by the spatial descriptions would enhance item retention and eliminate the serial position effect.

In Chapter 4, Experiment 2 will be presented. This study deals with the influence of a specific feature of the description – that is, the direction in which objects are introduced within a spatial description – on the processing of the description and the retrieval of spatial information. The rational of the present experiment was to investigate whether people construct a spatial mental model that is coherent with the direction of spatial descriptions, facilitating information retrieval and spatial reasoning.

The second part of the work is focused on the role of physical movement in supporting spatial processes. In Chapter 5, the characteristics of physical movement will be addressed extensively by clarifying the taxonomy of body–based information and by explaining the different contribution of cues derived from body motion. Moreover, a brief excursus will deal with different types of physical movements, mainly focusing on rotational and translational components.

In Chapter 6, the literature regarding the contribution of physical movement in spatial tasks will be reviewed, in particular the acquisition of spatial and mobility skills and the ability to keep track of previous experienced locations while moving in an environment by using spatial updating. This last aspect will be reviewed in detail, discussing its occurrence in remote environments and interpreting previous findings according to the most relevant models of spatial representation. Finally, the concept of the alignment effect will be introduced.

In Chapter 7, the role of physical movement on spatial reasoning in described environments will be presented. In particular, both theoretical approaches and empirical findings supporting the notion of action–grounded language will be extensively reviewed.

The last theoretical chapter of the second part, Chapter 8, will provide information regarding a particular case of spatial descriptions – that is the narratives – which describe fictitious environments in a narrative context. In light of the subsequent experiments, the influence of both the encoding perspective and the role of physical movement on spatial representations will be illustrated.

In Chapter 9, Experiment 3 will be reported. In this experiment we aimed to investigate whether three types of movements (i.e., imagined rotation, physical rotation and physical walking) differently affects spatial updating within described environments. Therefore, the influence of different multisensory patterns of information will be discussed according to the established theoretical frameworks.

In Chapter 10, Experiment 4 will be presented. This experiment deals with the contribution of different types of movement executed during the encoding of described environments. In particular, we aimed to investigate whether and how participants could benefit from the execution of physical walking during the encoding of described environments, in terms of enhanced spatial updating.

In Chapter 11, the findings of Experiment 5 regarding the contribution of physical movement on spatial navigation in a room–sized environment will be reported. In particular, we aimed to examine whether the body–based cues obtained during walking play a role in fostering spatial navigation.

Finally, Chapter 12 will conclude the present work, presenting a general discussion about the content of the thesis. In particular, the outcomes of our experiments will be extensively discussed and interpreted according to a common *fil rouge*. Furthermore, both theoretical and applied perspectives will be illustrated, providing interesting suggestions for future studies.

# PART I

# VERBAL DESCRIPTIONS OF ENVIRONMENTS

It is well–established that people have the ability to construct mental representations of a space by using a multitude of different information from the surrounding environment. However, in the situations in which information from perceptual experience (such as visual, auditory or tactile information) is lacking, people are able to employ abstract symbolic cues, such as maps or verbal descriptions, to successfully construct the corresponding spatial representation; in daily experience it is quite common to be exposed to maps or linguistically provided descriptions as support for exploration and wayfinding activities. Evidence from a growing number of studies suggests that verbal descriptions, in particular, are effectively employed to communicate spatial information in different situations, such as to distant people (e.g. provide road instructions via the phone) or to visually impaired people. The aim of this part is to examine the state–of–the–art of the studies regarding spatial representations derived from verbal descriptions of an environment, combining therefore aspects of text comprehension and spatial cognition.

# Chapter 1
# Theories of language comprehension

The influence of text comprehension abilities on spatial representations of described environments is critical, since readers/listeners need to adequately comprehend the verbal content of the spatial description to construct the corresponding spatial representation. Therefore, as a first step in this chapter, the most relevant theoretical approaches to language comprehension are introduced in order to provide a theoretical framework for the experimental findings in this research.

## 1.1 Mental Model Theory by Johnson-Laird

An influential theory for language comprehension was developed by Johnson-Laird (1980,1983), which assumes that the comprehension of a text leads to the construction of a corresponding mental model, that is, an internal model of the world having a similar structure to the corresponding state of affairs in the world. The process that determines the development of a mental model from a text goes through three representational levels: a graphemic representation, a propositional representation and a mental model. While the first level deals with the phonemic and graphemic features of the text, the second level considers the linguistic representation of the text; these two levels, being close to the surface qualities of the text, are not sufficient to determine the comprehension of the text. It is only at the third level that the propositional representation is turned into an analogical representation, the mental model, which represents the situation described in the text and not the text itself. Thus, the mental model represents information that goes beyond the fixed linguistic representation of the text, involving also the reader's/listener's experience. According to the author, the experience of the readers/listeners is necessary, since the inferences made by them – based on their previous experiences and from acquired world knowledge – also contribute to the comprehension of a text, together with the explicit information described in it.

The nature of the mental model can be defined as completely non–propositional, since it elaborates the features of the propositional representation in an analogical fashion, released from the constraints of the syntactic structure. Thus, the mental model contains the representation of the entities of the world, which are linguistically described in the text. It is easier to imagine the mental model as a network in which the elements that represent the objects or events in the world – named tokens – are related. Hence, the properties of the tokens in the model correspond to the properties of the entities in the world; similarly, the relations between the tokens in the model correspond to the relations between the entities in the world. Such a direct correspondence between tokens and world entities is further emphasized by the concept of *isomorphism* of the mental model to the world, evoking the non–propositional nature of the model: the contents of the mental model correspond to the events of the world and the structure of the mental model is analogous to that of the represented situation.

According to its analogical structure, the mental model seems similar to a mental image. Indeed, the mental images resemble iconic images with a degraded spatial structure, relying on low–level representations (e.g., Super, Spekreijse, & Lamme, 2001). However, a mental model does not correspond exactly to a mental image. As claimed by Denis and de Vega (1993), a mental image could just contribute to the construction of a mental model when the reader/listener encodes the text, by representing the described situation from a specific point of view. The mental model indeed represents the described situation from a different point of view, suggesting that it needs the contribution of a multitude of mental images to acquire all the necessary information. As soon as the model has been constructed, the mental image could also contribute to the instantiation of the model from the specific perspective it represents.

## 1.2 Other alternative theories for spatial text comprehension.

Even though the mental model's theory by Johnson-Laird (1980, 1983) effectively accounts for spatial text processing, other theories have been developed to explain the comprehension and processing of texts.

### 1.2.1 The Theory of Van Dijk and Kintsch

The theory postulated by van Dijk and Kintsch (1983) has often been associated with the theory of Johnson-Laird (1980, 1983), since they actually share some similar aspects, such as the three levels of the text representation. According to Van Dijk and Kintsch, the comprehension of a text goes through an initial word–to–word representation derived from the surface level, and a subsequent propositional text–based representation derived from the second level; this representation exhibits the microstructure and the macrostructure of the text. The comprehension process ends at the third level, where a situation model is constructed. The situation model – defined also as "a fragment of the world" (van Dijk, 1987) – contains the implicit information described in the text, which needs to be combined with the individual's knowledge of the world. Thus, the readers/listeners have to encode the literal meaning of the text as a function of their world knowledge. The inferences drawn by the readers/listeners are necessary for the mental representation of the text to be released from the linguistic constraints and go beyond what is literally expressed in the text, similarly to what happens in the mental model. The contribution of inferences leads some authors to assess text comprehension by testing the ability of the readers/listeners to produce inferences (e.g., Tardieu, Ehrlich, & Gyselinck, 1992; Taylor & Tversky, 1992a). Despite some common aspects, the situation model is not identical to the mental model, since the former can be defined as propositional (Kintsch, 1988; Kintsch, Welsch, Schmalhofer, & Zimny, 1990), whereas the latter is absolutely non–propositional, as previously discussed.

### 1.2.2 Theory of dual coding by Paivio

Another theory I would like to introduce does not specifically deal with text comprehension, however it seems to effectively explain the role of imagery in a text. The theory of dual coding (Paivio, 1971, 1986) postulates the occurrence of at least two coding systems, a verbal and a non–verbal system. Therefore, verbal and non–verbal stimuli are coded by the verbal and non–verbal systems, respectively. However, such a separation is not valid for a specific category of stimuli, that is, mental images (or pictures). Indeed, mental images are coded both by the verbal and the non–verbal systems, as they contain both a verbal and a non–verbal (e.g., visuospatial) characterization. As a consequence, mental images are memorized both in a verbal and a non–verbal form, causing the occurrence of two separate – but connected – memory traces. Such a double code process determines an enhanced recall for images and explains some of the effects found in previous research, such as the concreteness effect. According to Roche, Tolan, and Tehan (2011), concreteness seems to foster memory processes, affecting the number of items successfully recalled, since representations of concrete items contain more information than those of abstract items; indeed, concrete words, as mental images, are thought to maintain both a verbal and an imaginistic code. Even though Paivio’s theory effectively accounts for several memory effects, it does not provide a theoretical framework to explain the construction of a mental representation of a text.

# Chapter 2
# Spatial Descriptions

In the last decades a growing amount of findings concerning the construction of mental representations from verbal texts has been reported. Some authors focused specifically on spatial descriptions, namely verbal descriptions of an environment (e.g., Noordzij, Zuidhoek & Postma, 2006; Bestgen & Dupont, 2003). In particular, Franklin and Tversky (1990) introduced the concept of a past experience of space, claiming that it is a key aspect in the mental models constructed from complex descriptions of environments. Indeed, the experience of space acquired by people during their life seems to guide, and sometimes also to bias, the comprehension of a spatial text more than their perception. From now on, I will mainly focus on verbal descriptions of environments and on the corresponding spatial representations constructed from them.

## 2.1 The role of spatial descriptions in promoting an adequate spatial representation

The analogical nature of the mental model postulated by Johnson-Laird has been thoroughly examined by using spatial descriptions, determining an undeniable approval for the concept of a spatial mental model, that is, a mental model acquired from the verbal description of an environment. Starting from the notion of isomorphism suggested by Johnson-Laird, several studies have been completed to verify the effectiveness of spatial descriptions in supporting the construction of an adequate corresponding mental representation and to investigate the similarities between the mental representation of space derived from either direct experience or verbal descriptions.

Well–established findings suggest that people are able to construct spatial representations from simple verbal descriptions with spatial information (Cocude, Mellet, & Denis, 1999; Denis, Goncalves, & Memmi, 1995). It is noteworthy that some studies demonstrated that people construct spatial mental models containing information regarding the spatial relations and distances between described objects even when the spatial information is not explicitly described in the text (e.g., Rinck, Williams, Bower, & Becker, 1996; Bestgen & Dupont, 2003). Such a result could be explained by the contribution of inferences in the construction of the mental model (Johnson-Laird, 1980; 1983), allowing judgments about spatial relations (Uttal, Fisher, & Taylor, 2006) to occur.

Interesting suggestions about the characteristics of spatial mental models derived from verbal descriptions emerged from a study by Noordzij et al. (2006), even though their attention was primarily focused on the importance of visual experience. During the experimental procedure, sighted, early blind and late blind participants were asked to listen to two verbal descriptions and to execute two tasks aimed at investigating whether they had formed a linguistic representation or a mental model of the descriptions. In particular, the participants performed a priming/recognition task and a bird flight distance task. The former consisted of an old/new recognition task, in which the relation between the prime and target objects was manipulated into three conditions: close in text/close in space, far in text/close in space, far in text/far in space. Therefore, the authors manipulated the distances between the prime and the target objects described in the descriptions; such distances considered both the proximity in the text (e.g., prime and target objects were included in the same sentence) and the proximity in the environment described (e.g., the target object was directly next to the prime in the environment). In the second task, participants were asked to compare pairs of bird flight distances between objects in the considered environment (Denis & Zimmer, 1992).

Both tasks were employed to examine whether participants encoded verbal descriptions in a spatial or verbal form, since they are typically associated with specific response patterns which reveal a spatial organization of the mental representations derived from the considered environments. Hence, if people organize the verbal descriptions in spatial representations, a priming effect for spatial proximity and an inverse relationship between RTs and distance differences should be detected in the priming/recognition and the bird flight distance tasks, respectively. Noordzij et al. (2006) found patterns of results which are thought to reflect an implicit spatial memory strategy and, consequently, a spatial organization of the mental representation. The authors claimed that the representations constructed by the participants exhibited spatial features which reflected the features of the described environment – and not the features of the text itself. These outcomes strengthen previous evidence showing people’s abilities of constructing spatial representations from complex descriptions of unknown spatial configurations (Noordzij & Postma, 2005).

Once established that spatial descriptions are organized in a spatial mental model, another important issue to address concerns the structural coherence of the spatial mental models. Several researchers investigated whether such models preserve metric information, demonstrating that the spatial mental models constructed from verbal descriptions are actually similar to perceptual–based mental images, since they preserve the metric information, achieving structural coherence (Denis & Cocude, 1992; Denis et al., 1995). In order to verify the maintained structural coherence in models from verbal descriptions, some studies employed an image scanning paradigm.

The image scanning paradigm revealed the occurrence of a positive correlation between the time needed to mentally scan an image and the scanning distances (e.g., Beech, 1979; Borst & Kosslyn, 2008; Borst, Kosslyn, & Denis, 2006; Dror, Kosslyn, & Waag, 1993; Kosslyn, Ball, & Reiser, 1978; Pinker, Choate, & Finke, 1984) – namely, the image scanning effect – which is thought to reflect the structural isomorphism between the mental representation and the layout. These studies (e.g., Mellet et al., 2002; Chabanne, Péruch, Denis, & Thinus-Blanc, 2004; Afonso et al., 2010) required the participants to study a verbal description of an environment and to mentally scan pairs of landmarks. The results confirmed that spatial representations constructed from verbal descriptions accurately preserved the metric information, even if slight differences emerged depending on the perspective of the description (Chabanne et al., 2004 ). Moreover, the scanning of images derived from verbal texts activated the same cerebral areas (e.g., the parieto–temporal network) that are engaged when scanning images derived from vision (Mellet et al., 2000). The findings obtained by using the image scanning paradigm are in line with the notion of the functional equivalence of representations derived from verbal descriptions and perceptual experience (Avraamides, Loomis, Klatzky, & Golledge, 2004; Denis, 2008; Klatzky, Lippa, Loomis, & Golledge, 2003).

## 2.2 The functional equivalence hypothesis

### 2.2.1 Supportive findings

The functional equivalence of mental representations acquired through different sources of information has found confirmation in a multitude of experimental evidence (e.g., Loomis, Lippa, Klatzky, & Golledge, 2002). The explanation behind the functional equivalence of different sources might be connected to findings suggesting that at some point of the encoding process the source of encoding become worthless (Denis & Cocude, 1989). Thus, as soon as the mental representations have been constructed, the representations derived from different sources – such as visual, tactile, verbal inputs – are functionally equivalent and probably amodal (Bryant, 1997; de Vega, Cocude, Denis, Rodrigo, & Zimmer, 2001; Loomis et al., 2002). The amodal nature of mental images has been proposed by Bryant (1997), who claimed that such images represent information in an amodal format (that is, a format that is neither perceptual nor linguistic) which is generated by a common system from both perceptual and linguistic inputs.

An alternative explanation accounting for the functional equivalence hypothesis has been suggested by Loomis et al. (2002) according to their findings. Indeed, the authors asked blindfolded participants to perform a navigation task, that is, to walk towards a target object previously located through 3D sound or spatial language. The results for direct and indirect paths of walking were consistent among the encoding conditions, suggesting that the spatial representations formed were remarkably similar regardless of the different input modalities. Moreover, the authors interpreted these results as indicating the translation of spatial information about the target into a spatial image which was continuously updated during their walking; this happened independent of the modality of the information input.

As a consequence of these outcomes, Loomis et al. (2002) proposed a model of stimulus encoding and spatial updating, requiring an encoding and an updating stage. The encoding stage receives and processes the input in any modality and creates the corresponding mental image, while the updating stage is responsible for the updating of the egocentric relations as soon as they change. According to the input modality independence of the updating stage, the model postulated by Loomis et al. successfully accounts for the similar results found for different input modalities in spatial updating. However, the construction of a spatial image – which needs to be similar for linguistic and perceptual input – is essential to support the work of the updating stage and consequently, to determine the functional equivalence of representations from linguistic and perceptual input in spatial updating of both egocentric and allocentric relations (Avraamides et al., 2004). However, despite the assumption of functional equivalence of spatial images from different sources, this model does not examine and explain the nature of such spatial images. Some hypotheses suggest a visual format, which is updated by the imagined optic flow (Rieser, 1989) or an amodal format, as postulated by Bryant (1997).

It is noteworthy that the functional equivalence hypothesis has been accepted in the field of spatial cognition, since a remarkable amount of empirical findings was consistent with its assumptions. However, specific task requirements or the complexity of the environment described or even the quality of verbal descriptions might affect the validity of the functional equivalence of representations from linguistic or perceptual inputs; as a consequence, the effectiveness of verbal descriptions in supporting the construction of an adequate mental model might be limited too.

### 2.2.2 Controversial studies

Experimental studies mainly support the functional equivalence of spatial representations acquired through linguistic or perceptual input, although some exceptions still exist. Against the assumption of a spatial image independent from the input modality, evidence from the neurophysiologic domain seems to indicate that traces of the input modality are still present even after the complete construction of a spatial representation. Indeed, studies by Mellet et al. (2000; 2002) demonstrate that, during the mental image scanning, specific neural areas are selectively activated depending on the input modality. Moreover, Denis and Cocude (1997) failed to find spatial bias (such as performance asymmetries for salient and neutral landmarks) which is usually found in real environments, when examining described environments.

The encoding of verbal descriptions is exposed to the characteristics of the format. Indeed, the spatial relations included in a verbal description must be presented individually and following a sequential order out of necessity (see Levelt, 1982a), as verbal descriptions have a serial nature. Moreover, a visual format allows a greater degree of autonomy in selecting the relevant information, whereas a verbal description constrains people to a fixed selection of explicitly described information. Thus, spatial relations need to be elaborated and included in a format, such as a mental model, which goes beyond the limitations of the serial format. It is licit to assume that the processes required to encode an environment from spatial descriptions might be more demanding than directly perceiving it (Picucci, Gyselinck, Piolino, Nicolas, & Bosco, 2013). Even though the functional equivalence hypothesis accounts for similar representations from linguistic and perceptual inputs, it does not exclude that some representations might be more difficult to construct, determined by an increase in the observed response times (Klatzky, Lippa, Loomis, & Golledge, 2002; Péruch, Chabanne, Nesa, Thinus-Blanc, & Denis, 2006). Klatzky et al. (2002), for example, found that the construction of a mental model was slower when participants learned the location of items linguistically, than when they directly perceived them. The authors hypothesized that the increase in the response times might be due to the translation of the description into a spatial context. Hence, the construction of mental models from verbal descriptions relies on and is limited by the working memory capacity (see Gyselinck & Meneghetti, 2011; Pazzaglia, Gyselinck, Cornoldi, & De Beni, 2012, for a review). The already high cognitive demand of representations from verbal descriptions tends to further increase as a function of environmental complexity.

Verbal descriptions have been demonstrated to be effective in holding spatial information described within simple environments (Landau & Lakusta, 2009), however, other studies suggested increased difficulties as the environment complexity increased. Péruch et al. (2006) demonstrated that spatial representations from route verbal descriptions fail to retain metric properties of the environment when the task complexity increases, such as when the environment becomes more complex.

### 2.3 Characteristics of spatial descriptions: Focus on perspective

The fixed sequential nature of a verbal description limits readers' autonomous selection of the information described, but it also affects the ease with which readers construct the corresponding spatial representation. Zwaan and van Oostendorp (1993) identified three main conditions in a verbal text that can facilitate the construction of a spatial model. The description needs to be determinate – namely, describe a unique situation (Mani & Johnson-Laird, 1982) – continuous (Ehrlich & Johnson-Laird, 1982) – both at the spatial model level and at the text surface level – and condensed – namely, irrelevant information should not to be interposed with spatial information. In their study, the authors asked participants to read a complex, naturalistic text, stressing the need to process the information described in the text in a spatial format differently (i.e., reading with/without a specific spatial focus). The results suggest that people are not completely engaged in constructing and updating a spatial representation from verbal texts, unless explicit instructions to focus on spatial features are given to them. These studies provide further evidence suggesting that the construction of spatial representations is influenced by several factors, such as the requested task (see Hakala, 1999), the reader's expectations regarding the task (Noordzij et al., 2006) and the characteristics of the spatial descriptions (e.g. Shelton & McNamara, 2004).

As regards the characteristics of the descriptions, the aspect that has been mainly considered and studied in spatial literature is the influence of the perspective used in the text. The verbal descriptions of an environment can adopt two perspectives: egocentric (route descriptions) or allocentric (survey descriptions) perspectives. The route descriptions convey spatial information in an egocentric perspective, using an intrinsic reference frame that relates spatial information to the reader. Thus, the route descriptions use a first person perspective with egocentric terms (right, left) to guide the reader in an imaginary tour, in which the spatial information is described from the point of view of an observer moving within the environment. Survey descriptions, instead, convey information in an allocentric perspective, using an extrinsic reference frame that relates the described spatial information to other spatial information. Hence, survey descriptions use fixed cardinal directions (north, south, east and west) to describe the environment from an external, aerial point of view (Brunyé, Mahoney, & Taylor, 2010).

#### 2.3.1 The influence of text perspective on spatial representation

Even though people are able to form spatial representations from both survey and route descriptions (Noordzij & Postma, 2005), perspective seems to be a key aspect in the construction of a spatial model, since it has been suggested that the perspective adopted in a text anchors the readers in using the same perspective in the spatial model (Shelton & McNamara, 2004). Indeed, people seem to construct a spatial model from a spatial description, preserving the perspective of the original source. However, the issue of perspective–dependence or independence of a spatial model from a verbal description is still widely debated, since some outcomes suggest that spatial models are not connected to text perspective (Taylor & Tversky, 1992a). The inconsistencies of the findings have been attributed to representational formats (e.g., Shelton & McNamara, 2004), to test types (Péruch et al., 2006; Noordzij & Postma, 2005), to the experience with the environment, measured as the time spent to study the description (e.g., Sardone, Bosco, Scalisi & Longoni, 1995) and the familiarity with the described environment (Brunyé & Taylor, 2008a). As regards the study of Brunyé and Taylor, the authors examined whether the repeated exposure to verbal descriptions influenced the spatial model as a function of the description perspective; moreover, they investigated the occurrence of changes in reading times as a function of experience and description perspective. The results highlighted interesting differences depending on the perspective. In particular, the data showed that survey descriptions seem to be more directly translated into a spatial model than route descriptions. Indeed, people required extensive environment experience to construct a spatial model from route descriptions, whereas this was not necessary for survey descriptions. These outcomes are in line with previous studies suggesting difficulties in the construction of spatial models from route descriptions (e.g., Lee & Tversky, 2005; Noordzij et al., 2006) and indicating a more fine–grained object localization for survey than for route descriptions (Noordzij & Postma, 2005).

It is likely that the characteristics of route descriptions lead to a remarkable cognitive demand, which in turn affects the construction of a spatial model negatively. Brunyé and Taylor (2008a) proposed some possible explanations for the worse effectiveness of route compared to survey descriptions. The spatial relations contained in route descriptions are serially presented and therefore the serial organization may cause an increased cognitive demand while maintaining those relations in working memory during reading and updating (Shelton & McNamara, 2004). Indeed, it is possible that the impaired performance for route descriptions is due to the sequential processing style, as opposed to the simultaneous style of survey descriptions, which helps in integrating spatial relations as a whole (Ruotolo, Ruggiero, Vinciguerra, & Iachini, 2012). Moreover, route descriptions use an egocentric perspective with relative directions, which make them similar to past experiences of navigation. Consequently, route descriptions seem to encourage active egocentric imagery – namely imagination of someone moving inside the described environment – simultaneously with the reading of the descriptions. Therefore, some additional cognitive resources are allocated to such active imagery at the expense of the spatial model, whose construction has less resources available, especially when the environment is not well experienced (De Beni, Pazzaglia, Gyselinck, & Meneghetti, 2005; Deyzac, Logie, & Denis, 2006). Additional cognitive resources might also be assigned in response to the temporal–sequential nature of spatial relations, such as "after turning the corner" (Zwaan & Radvansky, 1998), further affecting the construction of a spatial model.

### 2.3.2 The influence of past experience on spatial perspective preference

As briefly outlined in these last sections, the ability to form an adequate spatial model from verbal descriptions partially depends on, or at least is influenced by, the individual's past experiences about spatial learning. During their life, people acquire learning strategies to encode and mentally represent the spatial information they daily face. For a sighted person, it is common to confront unknown environments (such as a new city or a new campus) by using a visual map, which represents the relevant spatial information (e.g., landmarks and their relations) in an allocentric perspective. In this framework, the preference for survey descriptions found for sighted participants should not come as a surprise; on the contrary, it could suggest a potential contribution of spatial learning strategies and modalities previously used. Therefore, by examining people with different experiences for spatial learning, it has been possible to acquire further interesting information regarding the construction of spatial models from route or survey descriptions.

The modalities through which people with visual impairments – that is, early blind, late blind and partially–sighted – encode spatial information from their surroundings are certainly different from those used by sighted people. While sighted people use mainly direct (such as viewing the surrounding environment) or symbolic (such as looking at a map) visual cues to encode spatial information, visually impaired people are physically obliged to use other kinds of cues, such as idiothetic and proprioceptive cues. As a consequence, the modalities through which visually impaired people encode spatial information – for example by using idiothetic and proprioceptive cues – turn out to be essentially egocentric, since they serially present spatial relations in an implicit reference frame relative to the person's position (Steyvers & Kooijman, 2009). Thus, visually impaired people might spontaneously form a spatial representation in which relations are contained in an egocentric perspective, similar to that derived from route descriptions. However, Noordzij et al. (2006) demonstrated that blind people are also able to construct spatial models preserving metric properties when learning the environment from verbal descriptions; actually, the results suggest that metric properties were slightly better represented in the spatial models of blind compared to sighted participants. Therefore, the authors suggest that a visual experience is not necessary to construct mental spatial models on the basis of verbal descriptions.

More importantly, they found evidence consistent with the hypothesis that blind people form less effective mental models than sighted people when exposed to a survey description, while the opposite trend emerged for route descriptions. Thus, even when blind people were able to encode spatial information in a survey representation (Tinti, Adenzato, Tamietto, & Cornoldi, 2006), they performed better when employing spatial strategies based on local route information (Millar, 1994; Thinus-Blanc & Gaunet, 1997), even when the required task explicitly favored a survey description. Thus, even though a visual experience does not seem to be essential to form a spatial mental model, only people with actual vision are able to construct an effective spatial model from survey descriptions. The results obtained by Noordzij et al. (2006) are consistent with previous outcomes, showing that sighted people prefer to give spatial information in an environment–oriented (allocentric) perspective, whereas blind people prefer an (egocentric) perspective related to their own position (Brambring, 1982). Taken together, these results support the assumption that the individual way in which navigation skills are learned and an individual’s experience with autonomous navigation are important aspects in the development of spatial abilities and significantly affect the preference for route or survey descriptions.

## 2.4 Working memory in spatial texts and the influence of text perspective

The organization and the functioning of the working memory (WM) have been extensively examined in different domains of cognitive sciences, since the working memory is involved in a multitude of activities. Baddeley and Hitch (1974) proposed a multicomponent model of WM which posits the existence of multiple subcomponents dealing with verbal and nonverbal material. The phonological loop is devoted to the storing and processing of verbal information, whereas the visuospatial sketchpad stores and processes nonverbal, visuospatial information. These subcomponents are coordinated by a third component, the central executive, which is mainly responsible for attentive functions, such as focusing attention, dividing it among multiple tasks and regulating the access to long term memory (e.g., Baddeley, 1986, 2007). In a subsequent review of his model, Baddeley (2000) added a forth component with limited capacity, the episodic buffer, which manipulates and stores information in short term memory by interacting with other subcomponents and with the long term memory. The episodic buffer plays an essential role in integrating information from components with different codes, showing consequently a shared multidimensional code. Moreover, since it carries out its binding functions rather passively, it leaves cognitive resources available for the central executive (Baddeley, Allen & Hitch, 2011).

### 2.4.1 Dissociation between verbal and visuospatial Working Memory subcomponents

The separation of the phonological loop and the visuospatial sketchpad entails that verbal and visuospatial materials are processed differently, reflecting different functional characteristics of the verbal and the visuospatial WM subcomponents. Empirical evidence from neuroimages and neural deficit studies supports the dissociation between verbal and visuospatial systems in short memory (e.g., Ravizza et al., 2006), even though other studies report controversial results (e.g., Öztekin, Davachi & McElree, 2010). Jones, Farrand, Stuart and Morris (1995) for example failed to find processing differences for verbal (letter names) and visuospatial (dot position) cues in a serial order reconstruction task, rejecting the separation of WM components in favor of a unitary WM model.

In addition to the studies which examined the differences occurring for well–established effects in the verbal and visuospatial domains (e.g., the serial position effect. Jones et al., 1995), the dissociation of WM subcomponents has been investigated by employing a selective interference paradigm. In the selective interference paradigm, participants are required to perform a primary task during the concurrent exposition to a secondary interfering task. Thus, if the tasks share the same processing subcomponent, they will compete for the same resources and performance will be impaired; however, if the tasks belong to different processing subcomponents, they will have enough resources and performance will not be touched. Since the secondary tasks have to be somehow related to the primary tasks to determine the interference effect, when examining WM dissociation, the primary task usually requires to read or listen to a text, whereas the secondary tasks specifically involve verbal or visuospatial WM functions. In particular, the articulatory suppression – that is, the continuous repetition of sequences of digits or syllables – affects the maintenance of information within the phonological loop, while the spatial tapping – that is, the continuous tapping of sequences of buttons – affects the maintenance of information within the visuospatial sketchpad (Farmer, Berman, & Fletcher, 1986).

### 2.4.2 Working Memory subcomponents for spatial descriptions

The model of Baddeley and Hitch (1974) is commonly used to provide a theoretical framework for studies concerning the role of the WM in processing spatial information and verbal descriptions. The contribution of the cognitive processes involved in the construction of a mental model from a spatial description has been widely investigated by a multitude of studies, revealing the important role of WM functions (e.g., Pazzaglia & Cornoldi, 1999). Moreover, the dissociation between the two subcomponents of WM has also been examined in the processing of spatial descriptions by observing the separate contributions of verbal and visuospatial components. Brooks (1967) was one of the first researchers who reported the involvement of spatial WM functions in the comprehension of spatial descriptions. The author presented participants with abstract or spatial sentences and demonstrated that the recall of spatial sentences was more impaired by reading than listening, whereas the opposite trend emerged for the abstract sentences. Brooks attributed these results to the concurrent competition of spatial processing and reading activity for the same cognitive resources available in the visuospatial sketchpad.

Many studies (e.g. Pazzaglia & Cornoldi, 1999) further extended the findings reported by Brooks, gathering additional evidence of the involvement of the visuospatial component of WM in the processing of spatial texts. Pazzaglia and Cornoldi (1999) employed concurrent interfering tasks (visual, spatial or verbal tasks) during the listening to various texts (visual, spatial and non spatial texts) and found the results consistent with the assumption that the processing of spatial texts necessitates both spatial and verbal functions. Moreover, their findings revealed that the visuospatial components can be further divided in visual, spatial–simultaneous and spatial–sequential subcomponents. These additional subcomponents seem to partially share the same resources and are more clearly separated from the verbal component (see the continuity model of WM, Cornoldi & Vecchi, 2003).

By using a selective interference paradigm, many studies successfully demonstrated that concurrent spatial tasks impaired people’s performances by interfering with both encoding (De Beni et al., 2005) and retrieval (Pazzaglia, De Beni & Meneghetti, 2007) of spatial texts. Conversely, the verbal tasks seemed to affect only the encoding of the texts. De Beni et al. (2005) required participants to listen to spatial and non spatial texts in different memory load situations, while performing concurrent verbal and spatial tasks. They found a significant interference in both verbal and spatial tasks during the listening to the spatial text, whereas the encoding of the non spatial text was compromised only by the verbal task. Therefore, they claimed that visuospatial and verbal WM components are engaged differently during the processing and memory of spatial and non spatial texts. A similar pattern of results emerged even when the concurrent spatial task was active during both encoding and retrieval of spatial texts (Pazzaglia et al., 2007; see also Brunyé & Taylor, 2008b).

In general, there are rather consistent findings supporting the involvement of the verbal and visuospatial WM in the construction of spatial mental models through verbal descriptions. Moreover, results found with the concurrent interfering paradigm can be interpreted according to three different explanations (Pazzaglia et al., 2012; Brunyé & Taylor, 2008b). First of all, as the visuospatial WM seems to be essential for spatial text processing and reactivation, the evidence found might support the assumption of the construction of a *spatial* mental model through verbal descriptions. Then, the concurrent tasks might interfere with the testing task, rather than with the reactivation of the spatial mental model. Finally, the participants might compute spatial inferences only when explicitly requested by the test, involving visuospatial WM resources.

### 2.4.3 The involvement of Working Memory subcomponents on spatial perspectives

As regards spatial descriptions, the perspective adopted to describe the items is a crucial aspect in spatial text comprehension, since it influences the construction of the corresponding mental model. The empirical evidence suggesting a different performance across multiple tasks in participants processing a route or a survey description has been already discussed (e.g., Lee & Tversky, 2005; Noordzij et al., 2006; Noordzij & Postma, 2005). However, some researchers examined whether different WM subcomponents underpin the processing of spatial texts from different perspectives. In light of the characteristic organization of route and survey texts, it is licit to expect that different functions of visuospatial WM would be recruited during the processing of spatial texts depending on the perspective adopted. Indeed, the comprehension of route descriptions requires the integration of linear–provided spatial information and is characterized by a continuous change of perspective; the comprehension of survey descriptions instead goes through the development of an initial global structure, in which landmarks are progressively positioned. Thus, those properties might be responsible for the involvement of different WM functions.

The selective interference paradigm has been employed to investigate whether spatial (Spatial tapping), verbal (Articulatory suppression) and sometimes visual (e.g., dynamic visual noise) concurrent tasks selectively impaired the recall of route or survey descriptions, as a demonstration of the involvement of different WM functions. In particular, Deyzac et al. (2006) asked participants to listen to survey and route descriptions while exposed to different concurrent interfering tasks. As for the concurrent tasks involving the spatial component of WM – namely, the spatial tapping – the authors found a stronger detrimental effect for route than for survey descriptions and consequently they claimed that participants listening to the survey description were able to mentally integrate spatial information, reducing detrimental interference (Exp. 1).

The authors interpreted the results according to the involvement of inner scribe and visual cache (Logie, 1995). They posited that the inner scribe actively processed the sequence of landmarks in the route description – which requires a landmark sequence – and this involvement determined the disrupting effect of the concurrent spatial tapping; however, the survey description – which requires landmark layout but not sequence – was not affected by the same task.

As regards the visual WM component, a dynamic visual task was employed (Exp. 3). The results indicated that the processing of landmarks was impaired by the task only in the route description, probably because of the visual imagery engaged during route texts. On the contrary, the memory of survey descriptions does not rely on visual strategies, such as the retrieval of images from long term memory, avoiding the impairment from concurrent visual stimuli. However, a passive visual task affected the route and survey descriptions similarly (Exp. 2). Finally, the data with verbal concurrent tasks – namely, the articulatory suppression – showed that the processing of both spatial descriptions did not require the verbal component of the WM (Exp. 4) suggesting the involvement of the phonological loop during the processing of landmarks in the survey condition.

Overall, Deyzac et al. (2006) demonstrated that route and survey descriptions rely upon different subcomponents of WM: mainly spatial and visual functions, and spatial and verbal functions, respectively. Similar results emerged in the study by Pazzaglia, Meneghetti, De Beni, and Gyselinck (2010, Exp. 1). By using articulatory suppression and spatial tapping concurrent tasks, they found a similar disruptive effect of the articulatory suppression task on both spatial descriptions, whereas the spatial tapping had a stronger effect on route than survey descriptions. Therefore, consistent empirical evidence seems to support the assumption of a dissociation between survey and route descriptions and provides indications regarding the WM subcomponents being directly involved in the processing of each spatial description.

A possible explanation of the dissociation between survey and route descriptions in the cited studies might lie in the specific properties of the two texts. Indeed, the route descriptions employ an egocentric sequential organization in which spatial landmarks are serially introduced from the protagonist’s point of view. On the contrary, the survey descriptions rely on an allocentric hierarchical organization, which consists in an initial description of the abstract configuration of the environment, which is filled in with the relevant landmarks. According to such different text properties and in light of previous empirical evidence (Pazzaglia & Cornoldi, 1999), it might be assumed that the processing of route and survey descriptions engage different subcomponents of the visuospatial WM.

The fractioning of the visuospatial WM into a spatial and a visual system is currently consolidated by researchers, however as reviewed by Pazzaglia et al. (2010), the assumption of separate visuospatial WM subcomponents has been tackled by multiple points of view. In particular, Logie (1986, 1995) posited the existence of the visual cache and the inner scribe within the visuospatial WM. The visual cache is a passive component, which is thought to be active during visual imagery tasks (e.g., Baddeley & Andrade, 2000); indeed, it is involved in the temporary storage of visual information such as the color and shape of objects. The inner scribe, instead, deals with motor spatial information and body movements and is actively involved in the rehearsal and transfer of information from the visual cache to the central executive.

Similar to the dissociation between an active and a passive system, other frameworks deal with the distinction between static versus dynamic processes (Pickering, Gathercole, Hall, & Lloyd, 2001) and with the differentiation between pattern encoding – responsible for global image processing – and a path encoding – responsible for spatial sequential processing of different positions (Lecerf & de Ribaupierre, 2005). A common pattern can be drawn by these frameworks, evoking the dissociation between simultaneous and sequential processes (Mammarella et al., 2006) required during the execution of different tasks: the recall of a fixed visual pattern and the recall of a serial spatial sequence, respectively.

In their study, Pazzaglia et al. (2010) hypothesized that previous evidence supporting the different involvement of visuospatial WM subcomponents during the encoding of survey or route descriptions might be interpreted according to the simultaneous versus sequential processes involved during the encoding of survey or route descriptions. Indeed, the specific properties of route and survey descriptions suggest a remarkable involvement of sequential processes for the online processing of route descriptions, while a significant involvement of simultaneous processes are required for the online processing of survey descriptions. By using a sequential or a simultaneous concurrent task, the authors found a different disrupting effect of the tasks on route and survey descriptions. The sequential task was more detrimental to the processing of route text than the simultaneous task, whereas the sequential and the simultaneous tasks similarly interfered with the processing of both survey and non spatial descriptions. Therefore, the study provides further evidence of the assumption that survey and route descriptions are processed differently, by focusing on an aspect so far neglected. Indeed, the authors claim that the sequential nature of the route description leads to the primary involvement of motor and sequential processes in the construction of the corresponding mental model.

## 2.5 Different types of spatial descriptions: previous evidence

Spatial descriptions convey information about the location of landmarks positioned in an environment and relate each landmark to the others in terms of spatial relations. It is well established that the processing of a spatial text determines the construction of a spatial mental model, which maintains the structural coherence with the environment and contains the features described. Moreover, the properties of the spatial description typify the corresponding mental model, since they guide its construction. In particular, the perspective (egocentric versus allocentric) employed in the description to convey spatial information has been demonstrated to be a crucial aspect in the process of encoding and recall of spatial information. However, spatial descriptions differ also for other aspects connected to the specific features of the considered environment.

As regards the scale of the space considered, Montello (1993) identified three behaviorally relevant scales of space: figural, vista and environmental spaces. A figural space refers to the space that has the size of objects, whereas a vista space refers to the space that has the dimension of a typical room. An environmental space refers to the space that cannot be seen entirely from one point of view. As the encoding of different scales of space might require the involvement of different processes, some studies examined whether the exposition of environments with diverse sizes would involve specific WM subcomponents. However, so far no evidence about the involvement of different WM subcomponents depending on the environmental scale emerged (for a detailed analysis about the relation between environmental and figural spatial abilities, refer to Sholl & Fraone, 2004).

Furthermore, the previous perceptual experience of a described environment might also affect the construction of a corresponding mental model. Indeed, when a text describes a familiar environment, people might rely more on the mental images contained in memory than on the information provided by the text. Therefore, the studies focusing on spatial descriptions mainly employed narratives, that is, (fictitious or real) environments that have never been experienced by the participants. In this situation, the participants have to construct a mental representation of the environment relying exclusively on the information contained in the description.

# Chapter 3

# Experiment 1. Spatial descriptions and the serial position effect

## 3.1 Introduction

The memory for serial order is essential for the management of high level cognitive activities (Hurlstone, Hitch, & Baddeley, 2014), influencing the ability to recall information independently of the position of the items. Cognitive studies have extensively explored the problem of serial order in different domains, employing different methodological procedures, and they repeatedly reported evidence consistent with the serial position effect. The serial position effect reflects the systematic changes in accuracy across an item's position, showing a significantly higher performance when responding to the first – primacy effect – and to the last items – recency effect – of a sequence (Olson, Romani, & Caramazza, 2010), whereas the middle items tend to be forgotten. The presence of the serial position effect is typically displayed by a U–shape curve, when plotting the recall accuracy as a function of the serial order of the items (Hurlstone et al., 2014).

An extensive amount of evidence has demonstrated the occurrence of the serial position effect in different situations involving the employment of verbal materials, such as letters and words (e.g., Tydgat, & Grainger, 2009; Bennet & Murdock, 1962). According to Hurlstone et al. (2014), the main use of verbal material in research dealing with the serial position effect may probably be due to the easy way in handling, that is, to build, manipulate and test verbal material compared to non–verbal material. On the other hand, it is possible that memory functions are sensitive to the stimulus domain (Fiore, Borella, Mammarella, & De Beni, 2012), showing different results in the non–verbal domain. As for non–verbal material, there are controversial results in studies using visuospatial stimuli.

The comparison between verbal and visuospatial material has not provided well–established and consistent results. Indeed, Cortis, Dent, Kennett and Ward (2015) found the same effect of serial order for both verbal and visuospatial material, claiming that different results across modalities found in previous studies could depend on the not–uniform methods used (Smyth, Hay, Hitch, & Horton, 2005; Farrand, Parmentier, & Jones, 2001; Ward, Avons, & Melling, 2003). Thus, their findings seem in line with the assumption of Guérard and Tremblay (2008), who proposed a functional equivalence of serial recall, with the suggestion that the serial order may be elaborated in similar ways across the domains (Hurlstone et al., 2014). However, despite providing encouraging results, there are some critical points in previous studies that should be considered. In Cortis et al.' study (2015), the overall accuracy differed between verbal and visuospatial stimuli and both primacy and recency effects were weaker for visuospatial than for verbal stimuli. Moreover, Hurlstone et al. (2014) highlighted that the serial position effect is well–established in the verbal domain, while further investigation is necessary in the visuospatial domain, due to not totally clear results. Thus, it seems that the serial position effect is more pronounced in the verbal domain compared to the visuospatial domain (Gmeindl, Walsh & Courtney, 2011).

It is interesting to note that in the visuospatial domain, different types of material were used to test the serial order influence, such as sequences of visuospatial locations (e.g., Farrand et al., 2001; Jones et al., 1995; Smyth & Scholey, 1996), and visuospatial movements (e.g., Agam, Bullock, & Sekuler, 2005; Agam, Galperin, Gold, & Sekuler, 2007). A multitude of different stimuli were employed, however to the best of our knowledge no study has investigated whether a verbal–spatial type of stimuli would determine the same pattern of results. In particular, there is no evidence clarifying whether the memory recall of items in a spatial description (i.e., verbal description of an environment) is affected by the serial order differently from the recall of items in a classic word list.

Previous evidence in spatial literature suggests that an environment verbally described is spatially, and not textually, encoded and fosters the development of a mental representation with the spatial characteristics described (Noordzij et al., 2006). Moreover, spatial descriptions seem to be functionally equivalent to directly perceived scenes, since they preserve metric information and structural coherence (Afonso et al., 2010). Previous studies suggest that serial order is more bound to verbal than to spatial information in working memory (Gmeidl et al., 2011), and that spatial information is strategically chunked in spatial local configuration (Bor, Duncan, Wiseman, & Owen, 2003). As a consequence, when encoding a spatial description we can expect two main scenarios. On the one hand, the spatial description is encoded as verbal information and will then rely on the serial position order; in this case, it would be exposed more easily to serial position effects. On the other hand, if the spatial description is encoded as spatial information it will be unbound to serial order and more prone to other strategies of organization. Thus, if the spatial description is encoded as spatial material, we should expect a response to serial order different to that typically shown by verbal stimuli.

An important factor that typically affects the recall of verbal items in a serial order is concreteness. Empirical evidence has demonstrated that concreteness and other features of the language, such as word frequency and lexical status, affect the number of items successfully recalled (Roche et al., 2011). According to the authors, concreteness seems to foster memory processes, since representations of concrete items contain more information than those of abstract items. In particular, concreteness strengthens item memories and consequently leaves time and resources available to process serial order. This effect can be interpreted according to Paivio's dual coding theory (1971), which assumes that concrete words maintain both a verbal and an imaginistic code. Moreover, it is consistent with the idea that using different types of information sources leads to better performance (Morin, Brown, & Lewandowsky, 2010). The concreteness of the items might be enhanced by including the items in a meaningful context; indeed it has been demonstrated that items are better recalled in a meaningful context than in a list (Bower & Clark, 1969). According to Brodsky et al. (2003), the logical structure which joins items seems to have a crucial role in organizing memory processes.

On the basis of our analysis, spatial coding and meaningful context are the two factors that might determine a different serial position effect for items encoded in a spatial description than in a word list. Indeed, the spatial description provides information relative to the spatial relations occurring between the described objects. Moreover, the described objects are included in a meaningful context, which enhances the ability to mentally visualize the described environment. Therefore, both the spatial coding and meaningful context characterise the spatial description. In order to determine the "pure" influence of spatial coding on the serial position effect of items included in a spatial description, it is necessary to verify the occurrence of the serial position effect on items described within a meaningful narrative, which provides no spatial information.

The aim of the present study is to investigate the occurrence of the serial position effect in the recall of items verbally presented in three different contexts: a classic word list, a spatial description of a room and a narrative without spatial information. We expect different accuracy distributions across item positions for the three contexts. In particular, we hypothesise that the spatial description will be encoded as spatial material, reducing the influence of the serial order and consequently determining a flattened U–shaped curve. Moreover, we hypothesise that the accuracy distribution for the spatial description will be different from the accuracy distribution for the narrative without spatial information.

## 3.2 Method

### Participants

Seventy–five university students (M = 19; F = 56) participated in this experiment in exchange for academic credits. Their age varied from 19 to 51 (M = 22; SD = 4.9). All participants were Italian native speakers. The participants signed the informed consent before starting the experiment. Participants were naive as to the purpose of the experiment.

### Experimental design

We employed an experimental design with two independent variables: Context (between subjects) and Position (within subjects). As regards Context, participants were randomly assigned to three conditions: List (L), Spatial (S) and Narrative (N). The Context variable refers to the context in which fifteen objects were verbally described in the learning phase. Indeed, in the List condition participants listened to a list of fifteen objects; in the Spatial condition participants listened to the description of a fictitious room, containing the same fifteen objects described in the list; in the Narrative condition participants listened to a meaningful narrative, in which the fifteen objects are described in a non–spatial context.

The Position variable refers to the position of the fifteen objects described in the three contexts. Indeed, the position of each object was kept unchanged across the three Context conditions. The fifteen objects were grouped in five clusters of three objects each. Then, the Initial condition refers to the first three objects (1–3); the Central condition refers to the three central objects (7–9); and the Final condition refers to the final three objects (13–15).

### Material

To provide participants with auditory information (narratives description and testing trials) we employed a notebook connected with Sennheiser HD515 headphones. The same notebook, running E–Prime 2 Software, was used to generate trials and perform the task.

## Stimuli generation

We chose fifteen words that were comparable in terms of both frequency use in the Italian language and number of letters. According to the experimental design, we manipulated the context in which the fifteen objects were presented. In the List condition the fifteen words were present in a sequence, whereas in the other two Context conditions the same words were included in a verbal description. Specifically, in the Spatial condition the words were included in the spatial description of a room, as for example “at the right corner, above the *carpet* on the floor there is a *pillow* and a backpack [...]”. Conversely, in the Narrative condition the words were part of a narrative without spatial information, as for example “I lie down on the *carpet*, leaning my head on the *pillow* [...]”. In a pilot study we tested the appropriateness of the descriptions provided. In particular, we tested the text comprehension difficulty in the spatial description and narrative; moreover, only for the spatial description, we asked participants to evaluate the ease in mentally representing the room described. The results confirmed the appropriateness of the description provided[1].

Both, the list of words and the verbal descriptions, were read by an experimenter and recorded. The time between two subsequent words was comparable across the three Context conditions in order to avoid any possible confounding effect of time.

**Procedure**

The experimental procedure consisted of a learning phase, in which participants listened to the objects (either in the list or in the descriptions), and a testing phase, in which participants performed an old/new recognition task. Participants were accompanied into a silent room, positioned in front of a computer and asked to wear the headphones.

The learning phase differed across the Context conditions, since participants were exposed to the fifteen objects described within three different contexts. In all the conditions participants were asked to carefully listen to the stimuli and to memorize them. No information was provided to participants as regards the subsequent task.

The testing phase started immediately after the learning phase. As soon as the list or the descriptions ended, participants were asked to observe the monitor and read the instructions explaining the following old/new recognition task. The task required participants to decide whether the acoustically provided words were old or new by pressing two alternative keys on the keyboard. There were thirty words: fifteen of them were the names of new objects and the other fifteen were the names of the objects previously heard in the learning phase. Participants were exposed to three repetitions of the words in random order. After each repetition participants were allowed to take a little break. Both accuracy and response times were measured.

Since the experimental procedure combined different types of stimuli (i.e. word list and verbal descriptions), we could not employ the test procedures commonly adopted with one of the two types of stimuli, such as free or serial recall (e.g. Ward, Tan, & Grenfell-Essam, 2010; Klein, Addis, & Kahana, 2005) and story retell procedure (Brodsky et al., 2003), respectively. Thus, to expose participants to the same test procedure in all conditions, we decided to employ a two alternative forced choice task (e.g., Broadbent & Broadbent, 1981; Phillips, 1983; Johnson & Miles, 2009; Gulya, Galluccio, Wilk, & Rovee-Collier, 2001).

[1] Fifteen participants were asked to evaluate the comprehension difficulty of both the narrative and the spatial description by using a 7–point Likert scale (1 meant "Not comprehensible" and 7 meant "totally comprehensible"). Mean scores of both the narrative (M = 6; SD = .84) and spatial description (M = 6.3; SD = .72) were statistically different from the central value of the scale and did not differ from each other. Similarly, the participants were asked to evaluate the ease in mentally representing the room (1 meant "very difficult" and 7 meant "very easy"). The mean score (M = 5.6; SD = .91) was significantly above the central value.

### 3.3 Data Analysis and Results

We calculated the proportion of correct responses for each item, and then the mean scores between the items belonging to the Initial, Central and Final conditions for each participant. Since we were interested in testing the serial position effect depending on the context in which the items were described, we considered for analysis only the results obtained for the words presented during the learning phase, but omitting the data for the new words.

*Accuracy*

As regards accuracy, we performed a 3 x 3 (Context x Position) repeated measures ANOVA, revealing a significant main effect of Context, $F(2, 72) = 11.912$; $p < .001$; $\eta^2 = .249$, a main effect of Position, $F(2, 144) = 3.505$; $p < .05$; $\eta^2 = .046$, and a significant interaction, $F(4,144) = 5.658$; $p < .001$; $\eta^2 = .136$. Planned contrasts with Bonferroni correction showed that participants were more accurate in the List and Spatial conditions than in the Narrative condition ($p < .001$ and $p < .005$, respectively), while the comparison between the List and Spatial conditions was only marginally significant ($p = .09$). Since the interaction reached a significant value, we ran further statistical analyses to better understand the direction of the effect; thus, we performed separate analyses for each Context condition (Figure 3.1).

As regards the List condition, a repeated measures ANOVA for Position showed a significant main effect, $F(2,48) = 10.012$; $p < .001$; $\eta^2 = .294$. Planned contrasts with Bonferroni correction revealed that participants were more accurate in the recognition of words in both the Initial and Final conditions than in the Central condition ($p < .001$ and $p < .05$ respectively), while no difference emerged between the Initial and Final conditions. Moreover, the statistics showed a significant quadratic trend, $F(1,24) = 17.155$; $p < .001$; $\eta^2 =.417$.

As regards the Spatial condition, we performed a repeated measures ANOVA for Position, which revealed neither a significant main effect nor a significant quadratic trend.

Finally, in the Narrative condition, we performed a repeated measures ANOVA for Position, finding a significant main effect, $F(2,48) = 4.103$; $p < .05$; $\eta^2 = .146$. Planned contrasts with Bonferroni correction revealed no difference either between the Initial and Central conditions or between the Central and Final conditions, while accuracy in the Initial condition was statistically lower than in the Final condition ($p < .01$). Moreover, no significant value was found for the quadratic trend, instead the data revealed a significant linear trend, $F(1,24) = 8.048$; $p < .01$; $\eta^2 = .251$.

*Response times*

As regards response times, we performed a 3 x 3 (Context x Position) repeated measures ANOVA, which revealed neither significant main effects nor significant interaction.

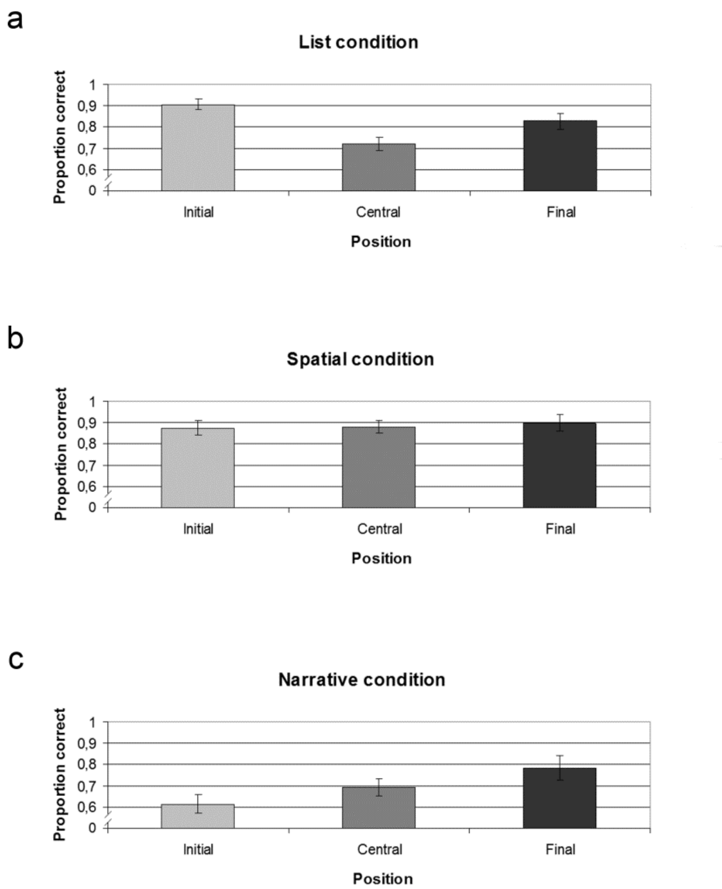


**Figure 3.1** Distribution of accuracy scores across item positions, for the List (a), Spatial (b) and Narrative (c) conditions. Bars show standard error.

## 3.4 Discussion

In the present study we aimed to investigate whether the occurrence of the serial position effect changes in the recall of items verbally presented in three different contexts. We expected different accuracy distributions across item positions for items described in the three contexts. In particular, we hypothesised a different accuracy distribution for the items, when they were presented in the spatial description compared to the list and the narrative description. The results confirmed our hypothesis.

As for the accuracy scores, we found a significant influence of the context on the overall accuracy, with generally higher performances for participants in the spatial condition. Moreover, interesting results emerged when data was examined separately for each Context condition. Consistent with the serial position literature (e.g. Bennet & Murdock, 1962), participants who listened to the list of words showed a significant decrease of accuracy for items in the central position of the list, confirming the occurrence of the typical serial position effect for word lists. Furthermore, the quadratic trend further confirmed the occurrence of the serial position effect, as shown by the U–shaped accuracy curve.

Conversely, a different pattern of results was found for the spatial condition. Indeed, the performance of participants who listened to the spatial description did not significantly change as a function of the position of the items, keeping a high accuracy score in each item position. The lack of the serial position effect might be due either to the meaningful context or to the spatial features; however, data from the narrative condition clearly demonstrated that a meaningful context does not elicit the maintenance of high accuracy scores across item positions. Indeed, differently from the spatial description, the performance of the participants who listened to the narrative gradually increased as a function of the position of items, as confirmed by the significant linear trend. Therefore, we can attribute the high accuracy scores across item positions (and consequently the absence of the U–shaped curve) in the spatial condition to the spatial features of the verbal description.

As for response times, we did not find significant results. However, in the analyses of the serial position effect the role of response times seemed to be less important than that played by accuracy. Previous studies on the serial position effect focused mainly on accuracy scores, suggesting that accuracy might better stress the potential effects related to the serial order of items. Indeed, many studies did not even report the results of the response times (e.g., Bennet & Murdock, 1962).

Overall, the results of the present study indicate that the accuracy distribution is affected by the serial order of the items depending on the context in which the items are presented. Consistent with our expectations, the spatial description provides a spatial framework in which the objects are encoded, overcoming the cognitive limitations that determine the serial position effect. Thus, our results are in line with the assumption that spatial descriptions are encoded as spatial information (Noordzij et al., 2006). Indeed, the accuracy distribution after the exposure to spatial descriptions is similar to that found for visuospatial material in previous studies, showing weaker primacy and recency effects than for verbal stimuli (e.g., Gmeindl et al., 2011; Cortis et al., 2015). Thus, our data indicate that spatial descriptions are unbound to the serial order of the items and are more prone to other strategies of organization, such as imagery strategies (see Pazzaglia et al., 2012). According to this interpretation, we might claim that the spatial descriptions behave like visuospatial stimuli, even though they actually belong into the verbal domain.

The performances obtained by participants while listening the spatial description can be explained by the Dual Coding Theory (Paivio, 1971), which postulates the occurrence of at least two coding systems, a verbal system and a non–verbal system. According to this theory, spatial descriptions might be coded by both, the verbal and non–verbal systems, as they contain both a verbal and a non–verbal (e.g. visuospatial) characterization. As a consequence, the spatial descriptions are memorized both in a verbal and a non–verbal form, causing the occurrence of two separate – but connected – memory traces. Similarly, although the meaningful narratives (without spatial information) should be memorized by both systems, however the different accuracy distributions of spatial descriptions and narratives could be attributed to the non–verbal system. Indeed, it is plausible that the spatial features of the spatial descriptions determine stronger visuospatial memory traces, compared to those elicited by the narratives. Alternatively, our results can be explained by Johnson-Laird's Mental Model Theory (1983). In this case, the spatial features of the spatial description determine a spatial mental model of the text (Tversky, 1993), which is probably more effective than the mental model evoked by the narrative.

From an applied perspective, it is noteworthy that one of the most common ways used to convey information regarding an environment is to describe it verbally. A verbal description is used for visually impaired people, but also for people who cannot directly perceive the environment, for example, when one has to describe a location to a friend over the phone. In such a situation, it is critical to report all available information and not to lose any part of the description, since this would mean getting lost or disoriented. Thus, our study provides new evidence supporting that spatial descriptions are an effective means to convey information, as we demonstrated that people are able to effectively remember the majority of the information included in the text. Even though further studies are necessary to prove that these conclusions can be generalized for different environments, the present outcomes encourage the use of this type of material to convey spatial information to people who are not able to directly experience an environment. Our results could be the basis for future research investigating how to organize the structure of the verbal description of an environment (e.g. Experiment 2).

In conclusion, the present study provides evidence demonstrating that the effect of the serial order of items changes depending on the context in which items are described. Whereas the word list determined a decreased accuracy for central items, a linear performance increment (from initial to final items) was observed when items were described in a meaningful narrative. Conversely, accuracy remained stable at high levels when items were described spatially, suggesting that spatial descriptions are processed like visuospatial stimuli, even though they originate in the verbal domain. Therefore, our results are in line with the assumption that the verbal description of an environment could lead to the development of a spatial mental representation, which facilitates item memorization and consequently reduces the serial position effect.

# Chapter 4
# Experiment 2. The influence of encoding direction on retrieval of spatial information

## 4.1 Introduction

Experiment 1 demonstrated that spatial descriptions are not affected by the serial position order, since they are encoded like a visuospatial stimulus. Therefore, listening to spatial descriptions, people seemed to be able to successfully remember the spatial information provided within the description, independent of its position. This evidence confirmed previous studies which revealed the effectiveness of spatial descriptions in communicating spatial information and encouraged us in dealing with further research. Therefore, it is well–established that people are able to construct spatial mental models when reading or listening to verbal descriptions of an environment. According to the theory of mental models (Johnson-Laird, 1983) the comprehension of a text is achieved through the development of a mental model, which is a working memory representation reflecting the objects, events or situations described in the text.

A fundamental assumption of Johnson-Laird's theory is the parsimony principle, according to which people try to minimize the cognitive load on working memory. In order to reduce cognitive demands, people tend to form only a single, simple model, integrating in it as much information as possible (Goodwin & Johnson-Laird, 2005). As a consequence of this principle, people rely on both instructions and characteristics provided by the text to construct a "preferred" mental model able to successfully capture the most relevant spatial configuration. The construction of a mental model is essential for communicative purposes, since people need to form a similar model to discuss it effectively. However, it seems that people share preferences guiding the construction of a preferred mental model (Garrod & Pickering, 2004); in particular, it has been demonstrated that people tend to form a mental model in which the described objects are positioned in a linear array, either horizontal or vertical (for a review, see Evans, Newstead & Byrne, 1993).

The linear disposition of objects within a mental model constructed through linguistic input, such as a verbal discourse, might be related to the properties of the input itself. Indeed, discourse has a linear nature (e.g., Levelt, 1982b): the order in which objects are introduced needs to be meaningful for both the sender and the receiver. However, the direction of the linear array seems to reflect a cultural bias, based on the daily practice of a given reading and writing direction (RWD). Such a practice determines a directional habit which progressively grows and solidifies, influencing the reasoning of people (Nachshon, 1985) and the directionality of their mental representations.

According to Román, El Fathi, and Santiago (2013), the habitual RWD seems to affect cognitive activities at different levels, such as word reading (Mishkin & Forgays, 1952), lateral motion perception (Maass, Pagani & Berta, 2007) number magnitude processing (e.g., Dehaene, Bossini, & Giraux, 1993) and time processing (Ouellet, Santiago, Israeli, & Gabay, 2010). Moreover, habitual RWD affects also behaviour activities, such as the choice of behavioural alternatives from a list (Ariel, Al-Harthy, Was, & Dunlosky, 2011) or the aesthetic choice of artists (Pérez Gonzales, 2011).

The effect of RWD on spatial representation has been studied by Jahn, Knauff, and Johnson-Laird (2007). They employed static spatial configurations, that is, a set of brief sentences describing static scenes, asking participants to evaluate the consistency of the set. The data suggested that the preference for an initial model ordered in a left–right fashion was due to the participants' habitual RWD. Thus, it is licit to expect that western individuals are more prone to exhibit a left–right (L–R) order organization, whereas individuals from other writing cultures, such as Arabic, are more susceptible to a right–left (R–L) order organization (Maas & Russo, 2003). A study by Román et al. (2013), in which Arabic and Spanish speaking participants were recruited, indicated that the directional bias depended on the degree of exposure, and consequently practice, in specific RWDs.

The directional lateral bias might be related to the development of perceptual motor habits, such as scanning and exploration, which might also be conveyed in internal representations (Maass, Suitner, Favaretto, & Cignacchi, 2009; Chatterjee, 2011). Conversely, the interpretation postulated by Román et al. (2013) embraced an alternative view, which is an extension of the coherent working models theory (Santiago, Román, & Ouellet, 2011). According to this theory, people are prone to visually represent the language content, even though the information is provided through an auditory modality. Moreover, consistent with the strategies dealing with the maintenance of working memory, the objects are included in the spatial model in the same order in which they are described. Another central element in the explanation provided by Román et al. (2013) is the principle of internal consistency: mental models are forced to be as internally coherent and simple as possible. Thus, it seems plausible that people prefer to organize spatial information in the same order in which the information was described within the text to minimize the memory load (Román, et al. 2013).

The cited studies mainly employed brief sentences describing spatial relations among three objects (e.g., Román et al., 2013), which were not included within a larger environment.

However, it is plausible that the same rationale might be applicable to mental models describing extended environments, such as room–sized spaces or parks. When people are, or imagine to be, positioned within an environment, they might be influenced by the same L–R order effect found for spatial sentences, determining a spatial information process which follows the left to right direction. However, when extended to a 360° surrounding environment, the L–R order direction results in a wider clockwise direction. Taylor and Tversky (1992b) demonstrated that people prefer to verbally describe an environment (e.g., Convention centre) by mentioning the relevant objects in a clockwise rather than a counter clockwise direction. The authors claimed that the clockwise order is another conventional order adopted by people and posited that this preference is part of the comprehension process and is necessary to construct a unique model from the verbal description.

It is noteworthy that in the study by Taylor and Tversky (1992b) participants learned an environment on a map, however we do not know whether the same preference would occur when learning an environment through spatial descriptions. Thus, we decided to provide participants with a verbal description of an environment, in which the objects were introduced following a clockwise or counter clockwise direction. The aim of the present study is to examine whether the direction in which objects are introduced within a spatial description affects the processing of the description and the retrieval of spatial information. In light of the L–R cultural bias we hypothesize a better reasoning about spatial relations when the objects are described in the clockwise direction.

## 4.2 Method

### Participants

Twenty–eight university students (M = 10; F = 18) were recruited for this experiment in exchange for academic credits; one male participant did not conclude the experiment. Their age varied from 19 to 26 years (M = 22.3; SD = 2.5). All participants were native Italian speakers and reported they had no hearing limitations. Before starting the experiment they signed the informed consent. Participants were naive as to the purpose of the experiment.

### Experimental design

We employed an experimental design with two independent variables: the direction of encoding (hereafter Encoding) and the direction of testing (hereafter Testing). Encoding and testing were manipulated between and within subjects, respectively. As regards Encoding, the participants were randomly assigned to one of the two conditions (Clockwise and Counter clockwise). The Encoding variable refers to the direction used to encode the environment; the participants were required to listen to the description of a room, which introduced the objects following one of the two directions.

The Testing variable refers to the position (Left or Right) of an object from the imagined position of the participant in each trial of the testing phase. Indeed, in each trial participants were exposed to sentences such as: "you are standing in front of the terrace, the dresser is at *your left*"; "you are standing in front of the terrace, the bed is at *your right*". The Left condition is when the named object is located to the left of the imagined position of the participant, which implies a counter clockwise reasoning. The Right condition is when the named object is located at the right of the imagined position of the participant, which implies a clockwise reasoning (see Figure 4.1).

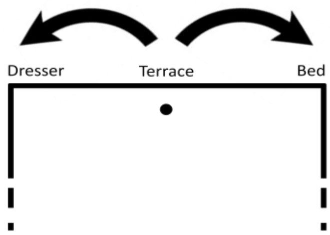


**Figure 4.1** A graphical representation of the environment layout and the experimental conditions as described in the text. The black dot represents the imagined position of the participant.

### Material

A notebook connected with headphones Sennheiser HD515 was employed to provide participants with the auditory information (verbal description and testing trials). Moreover, the same notebook, running E–Prime 2 Software, was used to generate trials and perform the experiment.

### Stimuli generation

Before starting the experiment, we created both a verbal description of the room and sentences for the testing phase. Both the verbal description and the sentences were in Italian and were created from a second person's point of view to foster participants' mental visualisation of the room.

#### *Description of the environment*

For the verbal description, two versions of a room containing eleven objects (see Figure 4.2) were created, according to the Encoding variable; the two versions introduced the same eleven objects either in a clockwise or a counter clockwise direction. The verbal descriptions were divided into four parts, one for each side of the room. Each part of the description was acoustically recorded. Before starting the experiment, we performed a pilot study to control for comprehension difficulties of the two versions of the descriptions and no differences emerged between them.

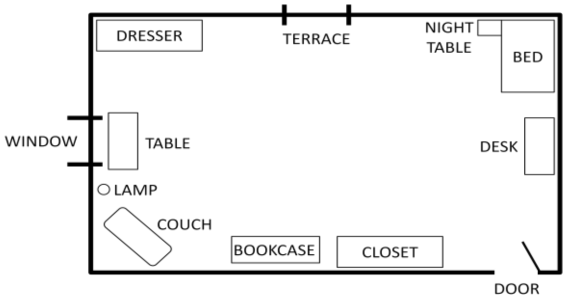


**Figure 4.2** Graphical representation of the environment described

*Sentences for testing phase*

Each sentence was composed of two parts, one regarding the position of the participant in the described room and one regarding the position of an object in the room. The first part of the sentence described the participant as standing in a specific location (e.g. “you are standing in front of the table”) or as entering the room (e.g. “as soon as you enter the room”), whereas the second part introduced an object as positioned at the right or the left of the participant.

Eight different positions of the participants were described in the first part of the sentence. For each of the eight positions we created four different versions for the second part, manipulating both the position (Left – Right) of the described objects and the correctness (True – False) of the sentences (see example in Table 4.1). Thus, we created thirty–two sentences: sixteen described the objects at the right of the participants (eight were true and eight were false) and sixteen described the objects at the left of the participants (eight were true and eight were false).

| First part | Second part | Direction – Correctness |
|---|---|---|
| You are standing in front of the window, | the closet is at your left. | Left – True |
| | the bed is at your left. | Left – False |
| | the bed is at your right. | Right – True |
| | the closet is at your right. | Right – False |

**Table 4.1** Prototypical example of how we created four different sentences, starting with the same first part.

**Procedure**

The experimental procedure consisted of a learning phase, in which participants listened to the verbal description, and a testing phase, in which participants performed a True/False recognition task. The participants were accompanied into a quiet room and asked to sit down comfortably in front of the monitor. Participants were then asked to wear the headphones and to read the instructions on the monitor.

In the learning phase the participants were required to listen carefully to either the clockwise or the counter clockwise verbal description and to mentally visualise the described room. Participants listened to each of the four parts of the description only once. After listening to the first part, when they were ready, they pressed a key on the keyboard to listen to the second part, and so on. Similar to previous studies (e.g., Avraamides, Galati, Pazzaglia, Meneghetti, & Denis, 2013b), the participants had the possibility to listen to the description one more time, to make sure that they had successfully understood the description and, consequently, could visualise the room. Only those participants who declared to have sufficiently understood the described environment were admitted to the testing phase. It is noteworthy that no participant was excluded from the experimental procedure for this reason.

In the testing phase, participants were asked to execute a true/false recognition task. The participants were exposed to thirty–two sentences in random order and asked to indicate whether each sentence was true or false by pressing two separate keys on the keyboard. Sixteen of the sentences were in the Left condition and sixteen in the Right condition; within each condition 50% of the sentences were true. We measured both response times and accuracy.

## 4.3 Data Analysis and Results

As regards accuracy, we calculated the percentage of the correct responses for participants assigned to the Clockwise and for those assigned to the Counter clockwise conditions, in both Left and Right conditions. We found that the percentage of accuracy was above the chance level for the Clockwise participants in both Left, $t(12) = 3.894$; $p < .005$; $d = 2.24$, and Right conditions, $t(12) = 5.376$; $p < .001$; $d = 3.1$, and for the Counter clockwise participants in both Left, $t(13) = 3.494$; $p < .005$; $d = 1.94$, and Right, $t(13) = 3.696$; $p < .005$; $d = 2.05$, conditions. Then we performed a 2 x 2 (Encoding x Testing) repeated measures ANOVA, which revealed no significant main effect nor interaction.

As regards response times, we calculated the average response time of the correctly performed trials for each participant in each condition. In the analyses we eliminated the outliers, considering the rule of 2 standard deviations as a criterion. A 2 x 2 (Encoding x Testing) repeated measures ANOVA revealed no significant main effect, but a significant interaction, $F(1, 25) = 4.732$; $p < .05$; $\eta^2 = .159$, emerged (Figure 4.3). Thus, we executed post–hoc comparisons and found a marginally significant difference between the Clockwise and Counter clockwise conditions, in the Right condition ($p = .07$) (see Figure 4.3).

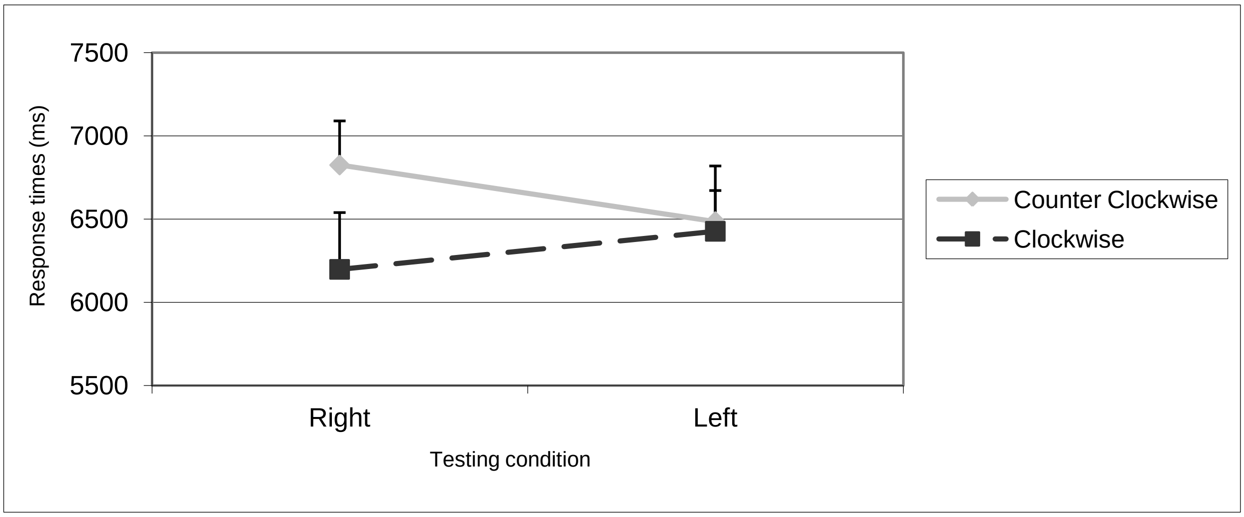


**Figure 4.3** Response times on Left and Right conditions, for each Encoding condition. Bars show standard error.

### 4.4 Discussion

The present study aimed to examine the influence of direction in which objects were encoded within a spatial description on their subsequent retrieval. Based on previous research (e.g., Taylor & Tversky, 1992b), we expected better results for information provided in a clockwise direction than in a counter clockwise direction. The results did not confirm our hypothesis. However, even though the analyses on response times did not reveal a significant main effect, we found a significant interaction. It seems that participants' response times were differently affected in the Testing conditions, depending on the Encoding conditions. In particular, the significant interaction indicates different patterns of participants' response times in the two groups of participants. Indeed, the participants who encoded the spatial information in the clockwise direction had higher average response times in the left (6426 ms) compared to the right (6197 ms) testing conditions; while the opposite occurred for participants who encoded the spatial information in the counter clockwise direction (left = 6484 ms; right = 6824 ms). The different pattern of response times for the two Encoding conditions is shown in Figure 4.3.

We can interpret the significant interaction in terms of congruency between encoding and testing directions. It seems that the response times of participants were negatively affected when the direction of the testing was incongruent with the direction of the encoding. Conversely, the response times of participants seemed to be positively affected when the direction of the testing was congruent with the direction of the encoding. Therefore, our study seems to extend the principle of internal consistency (Román et al., 2013) also to the domain of environmental space verbally described. Indeed, our outcomes are in line with the assumption that people endeavour to minimize the cognitive load on working memory processes (Román et al., 2013), by constructing the simplest and most internally coherent mental models. Constructing the simplest mental model means to choose the model which is expected to be the best at maintaining the relevant spatial relations. In the present study, it seems that spatial information was organized and maintained in the same order in which the information was described in the text. Thus, the preferred mental model for our participants would reflect such information organization. According to this interpretation, our results reject the idea of a cultural bias affecting the L–R preference as part of the comprehension process (e.g., Maas & Russo, 2003) for the verbal description of an environment.

As regards accuracy, our data did not show any significant main effect, indicating that the Encoding and Testing directions were not able to affect participants' accuracy scores. The average accuracy was above the chance level (.50) in each condition, confirming that the participants successfully executed the task required. However, even though the average accuracy was higher than chance level, it reached a low–medium value (ranging from .66 to .73), suggesting that participants encountered some difficulties when reasoning about spatial relations, independent of the direction of encoding or testing. Indeed, the participants reported that the task was quite hard to execute and that they needed a long time and a considerable amount of cognitive resources to solve it. Thus it is possible that by using a simpler task different results could emerge both in terms of accuracy and response times. Further research is needed to clarify this point.

In the light of previous studies revealing a preference of Western participants for reasoning in the clockwise direction, we expected a facilitation in spatial processing when the information was encoded in that direction. However, according to our data, neither the average response time nor the accuracy scores revealed a better performance for the participants who encoded the environment in a clockwise direction, than for those who encoded the environment in the opposite direction. Our outcomes suggest that spatial reasoning in described environments is not affected by the direction in which targets are encoded, failing to confirm the results found by Taylor and Tversky (1992b). It is noteworthy that their study employed a different experimental procedure, which probably is more similar to daily experience and consequently more effortless than our procedure. Thus, this difference might explain our failure to find a preference for the clockwise direction in both response times and accuracy scores.

Future studies should examine whether a preference for the clockwise direction would emerge if different encoding and testing stimuli were used. As for the encoding stimuli, it could be interesting to investigate whether the same pattern of results would emerge if the length and ease of the narratives were manipulated, namely with shorter/longer or easier/harder narratives, or if other sources of spatial information, such as a map, during the encoding of the narratives were introduced. Conversely, as for the testing stimuli, further studies should employ simplified testing sentences or even a different response modality to control for the cognitive load engaged during the testing phase.

From an applied perspective, the present study may provide important suggestions in the domain of visual impairment. Visually impaired people often cope with spatial difficulties by using verbal descriptions of the surrounding environment. Typically, verbal descriptions have to be processed by visually impaired people in non–optimal situations, namely when they are involved in other activities (such as walking) or when they are in noisy environments. For this reason, the way verbal descriptions are provided should be the easiest possible, to minimize their cognitive load. Thus, based on the evidence of our study, it is important that the initial description of an environment and the subsequent information provided (and/or requested) about the same environment are consistent with each other. In other terms, spatial information should be congruently provided and/or retrieved by always following the same direction. Nevertheless, we tested only sighted participants, thus future studies should verify whether visually impaired people would behave similarly to our participants.

In conclusion, we aimed to verify whether people prefer to reason about spatial relations in described environments from a clockwise or from a counter clockwise direction. Different to previous studies in other domains, it seems that spatial representation is not affected by the direction in which information is encoded and retrieved. However, it seems that the most important point is the congruency between the direction of encoding and retrieval. Thus, the present study suggests the extension of the principle of internal consistency within verbally described environments. This indicates that people construct a spatial mental model that is coherent with the direction of spatial descriptions, facilitating information retrieval from the same direction.

# PART II

# THE ROLE OF MOVEMENT IN SPATIAL COGNITION AND LEARNING

It is well known that the physical movement has a critical role in daily life, since it represents an important source of information, which contributes in guiding spatial processes, such as spatial reasoning, learning, encoding and updating. Even though the cues gained by physical movement are present in a multitude of activities (i.e., looking the surrounding while moving), it seems that people rely on the information gained through physical movement mainly when the primary source of spatial information – that is, the sight – is lacking. Thus, many studies investigated the effectiveness of physical movement – either executed alone or in combination with other information – in supporting the construction of spatial representations. In particular, according to some theoretical frameworks (e.g., the embodiment theory), the physical movement might be associated with spatial descriptions, positively affecting the consequent spatial representations. The aim of this part is to focus on the features of physical movement (for example, the different cues it provides, and the different types of movement) and to examine its contribution in spatial cognition. In particular, the role of physical movement within described environments will be investigated.

# Chapter 5
# The components of physical movement and their contributions

## 5.1 Taxonomy of body–based information

A multitude of common activities in human life comprehend the processing of spatial information, however people are usually so familiar with those activities to not even recognize the involvement of spatial tasks. If we consider activities such as orientating within unknown environments or moving within one's own house, we realize that people automatically perform those actions, maybe relying subconsciously on different sources of information.

Despite the availability of several sources of information, when people acquire knowledge about an environment, they lean on external (or allothetic) senses and mainly on vision, which conveys information regarding the layout of the surrounding environment, such as the number or location of relevant landmarks, and about the optic flow, that traces the changes in heading and position (Waller & Greenauer, 2007). It has been demonstrated that visual cues are effective in improving body stability while standing and walking and they modulate gait patterns, navigation and obstacle avoidance (Logan et al., 2010). Therefore, due to its reliability and effectiveness, vision might be considered as the primary source of spatial information devoted to spatial activities. People are so accustomed to rely on visual cues that they usually become aware of other sources of information only when deprived of vision.

When visual cues are lacking, other sensory systems accessible during human navigation emerge, namely the so–called body based (or idiothetic) senses. The body–based cues reflect internally generated signals about self–motion (see Arthur, Philbeck, & Chichka, 2009; Mittelstaedt & Mittelstaedt, 2001), since they derive from several sources involving the internal perception of body movements in space. The reference literature agrees in identifying the systems which seem to convey information regarding self–motion, but fails in proposing a shared taxonomy; however, multiple studies recognized that the vestibular system, proprioception and the efference motor copy are the principal sources of body–based information (e.g., Iosa, Fusco, Morone, & Paolucci, 2012; Frissen, Campos, Souman, & Ernst, 2011; Waller, Loomis, & Haun, 2004).

Before examining them, it is necessary to acknowledge that other studies categorized body–based information differently, focusing on other bodily signals. Even though Frissen et al. (2011) attributed the input generated by passive movement mainly to the vestibular system, they claimed that other information – such as optokinethic and podokinestethic information (Jürgens & Becker, 2006) – could derive from self–motion. According to the scope of the present work and consistent with spatial cognition literature, I exclusively refer to vestibular, proprioception and efferent copy information (and their combinations), aligned to the definitions provided below. At the same time, I acknowledge that studies in other fields deal with similar topics more extensively; unfortunately, for the sake of clarity and brevity, I choose to limit my discussion at a simpler level.

Vestibular information is responsible for the sense of balance and spatial orientation and is based on the structures of the inner ear, including those elements which detect angular and linear acceleration (see Angelaki, Gu, & DeAngelis, 2009); however, proprioceptive information is provided by sensory feedback coming from the movements of the muscles and joints (Lackner & Di Zio, 2005); finally, efferent motor information derives from movement motor commands originating in the central nervous system (Sperry, 1950) and is directed towards the musculature. Chrastil and Warren (2013), examining different components which might contribute to active spatial learning, focused on the same three components, namely vestibular, proprioceptive and efferent motor information, but also on their combinations. They defined podokinethic information as the association of efferent motor and proprioceptive information; they named idiothetic information (Mittelstaedt & Mittelstaedt, 2001) as the association of vestibular, proprioceptive and efferent motor information. The employment of the term "idiothetic information" to describe this specific multisensory pattern of information is well accepted in spatial cognition literature.

Even though in the present work I will follow the above mentioned definitions, it is important to note that an alternative classification has been proposed by Waller and Greenauer (2007). The authors divided the body–based senses – also named idiothetic senses – in two main categories: the proprioceptive and inertial cues. The former are in turn constituted by kinesthesis – movements of body parts – and efference copy, whereas the inertial cues comprehend primarily vestibular signals and then somatosensory and somatogravity cues. However, despite some slight differences, the relevant contents of Waller and Greenauer's definitions are similar to the taxonomy previously presented, suggesting a somehow–shared reference frame in spatial literature.

## 5.2 Different contributions from different cues

### 5.2.1 Visual–based and body–based information

In the last decades many studies focused on the different contributions of visual–based and body–based information, examining whether some cues are more effective in enhancing spatial activities among sighted (and visually impaired) people. Moreover, the specificity of each body–based information has been investigated to understand what component is necessary or sufficient for spatial tasks. Since this argument can be seen from different points of view, diverse paradigms and slightly different aspects have been examined according to the areas of expertise.

As regards the former aspect examined in previous studies – i.e. the differences between visual and body based information – the results seem to be controversial. Ruddle and Lessels (2009) investigated the benefits of body–based information, declined as rotational and translational components, on a navigational task in a virtual environment. They found that participants who had full body–based information – acquired by walking in a room while wearing a head–mounted display (HMD, that is, the display showed the virtual environment) – showed a better performance compared to those who had visual cues only; moreover their performance was similar to that reported in tasks executed in the real world (Lessels & Ruddle, 2005). Furthermore, walking prevented participants to collide with obstacles in the environment explored. When the authors impoverished the visual scene provided to the participants through HMD (Experiment 2), the outcomes indicated that a rich visual scene is not necessary for navigation, since the performance of the participants did not change depending on the visual details provided. The evidence found by Ruddle and Lessels (2009) is in line with previous studies suggesting that visual information is not sufficient to effectively navigate in virtual environments (Witmer, Bailey, Knerr, & Parsons, 1996; Ruddle, 2001). Indeed, it is commonly believed that additional body–based information is necessary to maintain awareness of spatial orientation (see Kearns, Warren, Duchon, & Tarr, 2002; Riecke, van Veen & Bulthoff, 2002).

Conversely, other empirical evidence revealed that in some situations visual cues seem to be sufficient for the learning of the environmental layout. The data found by Warren and Greenauer (2007) supports the assumption that purely visual sources are effective in spatial layout learning of large scale environments, without the additional support of bodily signals (e.g., Rossano, West, Robertson, Wayne, & Chase, 1999). Indeed, they found just a minimal role of body based (idiothetic) information for spatial learning in a large scale environment. However, Chrastil and Warren (2013) defined the path employed by Warren and Greenauer as a simple environment and consequently suggested that vision may be enough for spatial learning in simple environments.

The requirement of additional cues from body senses was also investigated by Waller et al. (2003, 2004), who performed two consecutive experiments dealing with the role of inertial and body–based information for enhancing environment knowledge. In the first study (Waller, Loomis, & Steck, 2003) participants learned the layout of a large environment under conditions which differed, depending on the degree of the inertial cues available. Thus, the participants learned the environment while seated on the back seat of a car with full visual cues (full cues), or by looking through an HMD (inertial cues), or by looking through an HMD with non matching images (non matching cues); the last group of participants watched the images through the HMD while seated in the laboratory (video cues). The results indicated a higher accuracy at judging relative distances for participants in the full cues condition compared to the other conditions. Moreover, the other conditions (inertial, non matching and video) did not differ in any measure of spatial knowledge used. Therefore, a weak – if not absent – effect of inertial cues on the acquisition of an environmental layout emerged, since the availability of matching or non–matching or absent inertial cues did not influence the accuracy in remembering spatial relations.

In their second study (Waller et al., 2004), participants were asked to learn a spatial layout by walking through an environment with HMD (walking condition), or by watching the video of a trip within the environment while sitting in the laboratory (sitting condition) or by watching a special video, which reduced the optic flow derived from head rotations (smooth condition). Their findings revealed that body–based cues – derived primary from proprioception and efferent motor movements – seem to be employed in the active learning of large environments and in its enhancement. However, the slight statistical differences found for the pointing task and the lack of effect found for distance estimation and map construction suggests that the effect of body–based cues on environmental configuration knowledge may be minimal.

### 5.2.2 Contribution from different sources of body–based information

Several studies attempted to isolate the contribution of each component of body–based cues in order to examine what component would facilitate the acquisition of spatial knowledge. As previously stated, Waller et al. (2004) hypothesized that proprioception and efferent motor movements were the primary sources of information contributing to body–based cues. Indeed, active bodily movements, which convey both proprioceptive, efferent motor and vestibular information, seem to be effective in supporting spatial perceptions in spatial tasks (Yardley & Higgins, 1998; Jürgens, Boß, & Becker, 1999).

The role of these sources of information and their interaction has been extensively investigated in different contexts, such as spatial updating (Frissen et al., 2011) or estimation of spatial distances and directions (e.g., Mittelsteadt & Mittelsteadt, 2001; Butler, Smith, Campos, & Bülthoff, 2010). Many studies revealed that both proprioceptive and vestibular cues could be employed independently (Jürgens & Becker, 2006) and that they were sufficient for a task requiring to estimate travelled distances (Berthoz, Israël, Georges–François, Grasso, & Tsuzuku, 1995; Mittelsteadt & Mittelsteadt, 2001) when available separately. Furthermore, each type of cue seemed to have its own specificity: for example, vestibular cues were sufficient to support the estimation of an egocentric heading direction (Butler et al., 2010). However, when proprioceptive and vestibular cues appeared simultaneously, the proprioceptive cues seemed to dominate vestibular cues. The concurrent exposition of proprioceptive and vestibular cues determines the occurrence of multisensory integration, due to the weighted average calculation of the contribution of cues performed by the brain structures (see Becker, Nasios, Raab, & Jürgens, 2002). Conversely, some researchers believe that the integration of different bodily cues occur in a statistically optimal way (e.g., Cheng, Shettleworth, Huttenlocher, & Rieser, 2007), resulting in the most reliable estimation given the available inputs. The integration of sensory cues is crucial since a multitude of activities is supported by different cues. Walking in particular is characterized by a very tight connection of both proprioceptive and vestibular information, which makes it hard to dissociate them.

Based on previous findings, Frissen et al. (2011) examined how proprioceptive and vestibular information are integrated in a walking task. Therefore, they proposed three conditions in which the contribution of those signals was manipulated. In the passive movement condition (wheelchair), participants were exposed primarily to vestibular inputs, since no relevant proprioceptive cues emerged from the legs. In the walking in place condition, participants were provided primarily with proprioceptive information, since no relevant vestibular input came from linear translation. Finally, in the walking through space condition, both signals occurred. Their results suggest that people use both vestibular and proprioceptive signals in spatial tasks, and the latter alone are not sufficient to support the experience of navigation through space.

Even though the findings obtained by Frissen et al. shed light on the different contributions of body–based information, they did not systematically report the role of efferent motor cues, probably because they considered them as part of the proprioception (see Waller & Greenauer’s classification). Conversely, referring to the definitions proposed by Chrastil and Warren (2013), the term podokinethic information is used to indicate the combination of proprioceptive and efferent motor information. As a consequence, some confusion might arise when looking at different empirical contributions, since the same (or different) terms convey different (or the same) meanings.

As regards idiothetic information, several studies focused on the contribution of cues derived from active bodily movements on spatial learning. As for spatial navigation and learning, it seems that visual information is sufficient to learn small environments, whereas a idiothetic contribution is required for larger environmental knowledge (e.g., Ruddle, Volkova, & Bülthoff, 2011; Waller & Greenauer, 2007). On the basis of their previous studies suggesting that participants who walked were more accurate than those who watched the videos (Waller et al., 2004), the authors separated the contribution of podokinetic, vestibular and visual cues on spatial updating. The outcomes revealed that the idiothetic contribution derived from podokinetic information (Mellet et al., 2010) and not from vestibular information. It may be assumed that podokinethic cues are responsible for the environmental layout learning and consequently, spatial exploration (Chrastil & Warren, 2013), supporting therefore the role of idiothetic information to help people keeping track of the explored location.

## 5.3 A clarification for rotational and translational information

When referring to body–based information, a further distinction needs to be made regarding the components of movement. Indeed, prioprioceptive, vestibular and motor efferent information refers to the specific information gained by physical walking, whereas rotation and translation refer to specific components of physical walking. Many studies have examined whether rotational and translational movements affect people's performance differently in spatial tasks, since they do not convey the same cues. However, it is rather easy to isolate these two components during the experimental procedure in both the real world and a virtual environment (e.g., rotate in place or walk linearly without rotating the body axes), facilitating the interpretation of the empirical results. Empirical evidence reports different effects of rotation and translation on spatial tasks.

The significant benefits of rotation have been demonstrated on a multitude of basic spatial tasks, such as turning according to a prescribed angle (Bakker, Werkhoven, & Passenier, 1999) and pointing to an object previously seen from another object (Lathrop & Kaiser, 2002). However, these advantages of rotational movements did not occur when performing complex tasks (Ruddle & Péruch, 2004), indicating that rotational information is not sufficient to effectively support people during navigation in large and complex environments (Ruddle, 2001).

The translational component has been investigated in virtual environments by using walking in place algorithms or linear treadmills (e.g., Hollerbach, Checcacci, Noma, Yanagida, & Tetsutani, 2003). However, only a slight beneficial effect of translation emerged for human navigation (e.g., Grant & Magee, 1998).

# Chapter 6
# The importance of physical movement in spatial tasks

## 6.1 Individual mobility skills

According to Creem and Proffitt (1998, 2001), two separate systems are responsible for the processing of spatial information. The cognitive system elaborates the incoming spatial information and contains the corresponding internal representations, and the perception–action system collects information from guided action and motor responses. In this framework, an active–movement component is clearly associated with the cognitive component, both contributing to meet and solve spatial requirements. Past studies reported outcomes showing that autonomous experience of movement in an environment facilitates spatial knowledge acquisition both in young children (Feldman & Acredolo, 1979) and adults (Thorndyke & Hayes-Roth, 1982) and supports the formation of orientation–independent spatial memory (Evans & Pezdek, 1980). Indeed, physical exploration supports the development of rich and integrated spatial representations (Golledge & Spector, 1978) by using computational techniques, such as computational modeling of wayfinding (Kuipers, Tecuci, & Stankeiwicz, 2001).

The importance of physical movement emerges more clearly when studying situations in which visual cues are absent. In those situations people gain spatial information by means of essentially egocentric perceptual modalities (Cattaneo et al., 2008), which seem to facilitate the construction of route–like representations (Ruotolo et al., 2012). Therefore, many studies recruited visually impaired persons, and among them totally blind persons, in order to examine the weight of physical movement in purely without–vision circumstances (e.g., Loomis et al, 1993; Ungar, Blades & Spencer, 1996; Schmidt, Tinti, Fantino, Mammarella, & Cornoldi, 2013).

In particular, the development of an individual's mobility skills seems to be related to the employment of different spatial strategies (Loomis et al, 1993; Ungar et al., 1996), consequently affecting the individual's spatial competences. Loomis et al. (1993) claimed that individual spatial skills may depend more on one's own past experience in active navigation than on previous visual experience. In this framework, motor education during childhood seems to be a crucial factor in the development of adequate spatial abilities (Ochaita & Huertas, 1993; Loomis et al., 1993). Indeed, when young children are educated to autonomously explore an environment, they are exposed to situations with different demands (such as bypass an obstacle or find new paths from a novel starting point), which require them to adapt known strategies to their new needs. In this way, children are encouraged to face new environments and to tackle challenging spatial requirements (e.g., moving autonomously in the neighborhood), developing as a consequence adaptable and flexible spatial strategies. Moreover, by comparing blind and sighted participants' performances in the construction of spatial representations from verbal descriptions, Schmidt et al. (2013) found that autonomous (in terms of daily mobility) blind participants tended to use imagery strategies similar to those used by sighted participant, but different from non autonomous blind persons. Therefore, the authors suggested that by working on the independent spatial navigational skills of non–autonomous blind people, it might be possible to improve their ability to construct an effective spatial representation.

## 6.2 Spatial updating

Spatial processes are closely related to physical movement, since in daily life people have to act in a world in which spatial relations constantly change as a function of the observers' or objects' movements. The ability to keep track of the changing spatial relations between the self and the main objects when moving within an environment is defined as spatial updating (Pick & Rieser, 1982). A typical paradigm consists of providing participants with a layout of various objects at different locations and asking them to point to an object after changing their position of the direction they face (Easton & Sholl, 1995; Presson & Montello, 1994). However, spatial updating has been widely investigated by manipulating a multitude of factors (For a detailed review, I recommend Creem-Regehr, 2004). In particular, it has been examined by using different paradigms (ignore task versus updating task), by providing different cues (non visual versus visual locomotion) and by examining different typologies of movement (body versus object or environmental movement).

A well–established amount of empirical evidence demonstrates that updating spatial relations with the surrounding is significantly easier to perform when actually moving than when imagining the same movement (e.g., Rieser, 1989; Wang & Spelke, 2000). Indeed, spatial updating seems to rely on idiothetic information, since it occurs when idiothetic cues are available. When provided with those cues, that is, when moving, people seem to be able to effortlessly update spatial relations of objects surrounding them, namely of objects located within their immediate environment (Klatzky, Loomis, Beall, Chance, & Golledge, 1998). This assumption is confirmed by studies executed by using a virtual environment, showing that information from body rotation supports a spatial localization performance better than the visual information gained by looking at the movement of the environment (e.g., Chance, Gaunet, Beall, & Loomis, 1998).

Therefore, as suggested by Rieser (1989) physical movement might be a fundamental prerequisite for online spatial updating, since the idiothetic information conveys the necessary cues to monitor all the relevant spatial changes. The term online spatial updating has been used by Avraamides et al. (2013a) to indicate the spatial updating that occurs effortlessly during physical movements and to distinguish it from the spatial updating that requires a remarkable cognitive load and occurs when people just imagine a movement or when they stay still.

### 6.2.1 Spatial updating after body motion: rotation and translation

Spatial updating occurs rather easily during physical movement, however such a facilitation may be due to either rotation or translation or both. Thus, some studies focused on the role of these different components of movement in spatial updating (e.g., Rieser, 1989; Presson & Montello, 1994). Presson and Montello (1994) claimed that the outcomes from those studies have important implications for comprehending how spatial information is coded in the WM during real or imagined movements (computational approach versus two–dimensional Cartesian reference frames).

The different ease in spatial updating after rotation or translation has been examined by Rieser (1989), who reported a greater difficulty in updating after an imagined rotation than an imagined translation, and consistently a better performance (that is, lower latencies and higher accuracy) after an imagined translation than after an imagined rotation. By using a more constrained procedure, Presson and Montello (1994) confirmed the previous results, demonstrating that spatial updating after an imagined rotation was harder than after an imagined translation, which in turn resulted to be similar to the real movements. The authors, consistent with previous studies (e.g., Franklin & Tversky, 1990), posited that spatial working memory seems to be organized around an ego–centered Cartesian axis. Hence, these results may be explained by using ego–centered reference frames. People seem to rely on their actual location and orientation – that is, their primary reference frame – when planning actions; however when asked to imagine a rotation, people have to shift from their primary frame to a secondary frame of reference, while during an imagined translation their secondary reference frame is actually parallel to their primary reference frame (due to the same heading direction). Therefore, the reported difficulty for an imagined rotation is explained by a conflict between the primary and secondary reference frame, which is eliminated for the real rotation by aligning the two frames.

### 6.2.2 Spatial updating for remote environments

It is well established that spatial updating occurs in an effortless manner in immediate environments, because of the multisensory cues (e.g., idiothetic and visual flow) which convey information regarding the changing relations. However, people sometimes are required to update spatial positions while reasoning about a remote environment, namely an environment not directly perceived at the time of testing. Therefore, many researchers investigated whether spatial updating emerges even when the processing location lies beyond the immediate environment and how physical movement affects it.

Previous studies reported that people are able to update spatial relations in a remote environment, but the updating does not seem to occur online: evidence suggests that even if people update spatial relations on demands, they fail to execute the updating during movement (Wang & Brockmole, 2003a, b). This result can be interpreted by postulating that spatial relations of the immediate environment are maintained in a transient egocentric representation, which is impaired by disorientation (Waller & Hodgson, 2006) and in which the spatial updating operates. The spatial relations of a remote environment are instead encoded in an enduring representation, which is immune to disorientation. Moreover, the enduring representation is detached from one's own body position and orientation, preventing the beneficial effects of physical movement. Indeed, physical movement cannot link the remote objects contained in the enduring representation with the sensorimotor framework.

Therefore, the detachment between enduring representations and physical movement seems to be responsible for the demanding processing of spatial updating in remote environments. The role of physical movement in spatial updating of remote environments already emerged in a study performed by Rieser, Garing and Young (1994), in which children and their parents at their home, were asked to visualize the classroom and to indicate some objects both from the child's seat and from the teacher's seat. When participants were asked to imagine the movement from the child's to the teacher's seat (that is, to walk towards the seat of the teacher and then to rotate adopting the usual teacher's facing orientation), the results were not encouraging. Indeed, parents were slower in indicating the required directions from the teacher's rather than from the child' seat, and children were both slower and less accurate. Conversely, when participants were asked to physically walk the imagined path going from the child's to the teacher's seat, their performance improved significantly, showing the same performance in both perspectives. A study by Wang and Brockmole (2003b) further reinforces the previous results; the authors demonstrated the occurrence of online spatial updating for remote relations after a physical movement that was explicitly connected with objects in the remote environment (i.e. when participants rotated towards the imagined location of objects in the remote environment). This indicates that online spatial updating in a remote environment is possible when executing a physical movement that is explicitly connected to the objects located in the remote environment. Taken together, these studies suggest that by means of physical movement and visualization instructions, objects located in a remote environment are considered as immediate objects (Wang, 2004; Kelly, Avraamides & Loomis, 2007, Experiment 3).

The studies just cited used a familiar context (the campus landmarks and classroom) as a remote environment, which might have helped participants in their performance. Indeed, familiar environments are encoded in memory from different orientations because of the acquired experience from multiple perspectives; thus, previous findings in familiar environments might be determined by the retrieval of environmental representations from memory and not by updating abilities. The processing of an unfamiliar environment however requires a cognitive effort, which may influence the spatial updating. To disentangle the interpretation of previous results, Avraamides, Galati and Papadopoulou (2013a) examined spatial updating in unfamiliar remote environments and found comparable pointing accuracy from all the perspectives adopted when participants were allowed to physically rotate, confirming online spatial updating. Furthermore, participants were faster in pointing from the learning perspective compared to the other perspectives, indicating that they maintained an orientation–dependent representation at encoding (McNamara, 2003).

### 6.2.3 Representational systems of spatial memory and updating

The results found in spatial updating tasks have been explained in different ways and a few detailed accounts emerged to explain the underlying organizational structure of spatial representations. Initially, Rieser (1989) interpreted the difference of ease in updating spatial relations in immediate and remote environments according to a mental transformation hypothesis. Indeed, the author claimed that spatial updating in remote environments can occur even without proprioceptive signals if the person deliberately computes the new egocentric positions of items. However, this calculation is cognitively demanding and therefore taxes the available resources, resulting in an effort of offline spatial updating. Conversely, May (2004) proposed a sensorimotor interference hypothesis. According to this hypothesis, the impairment in reasoning from imagined movement is due to an interference derived from two sources: ODD (Objects Directions Disparity – misalignment of physical and imagined object positions) and HDD (Head Direction Disparity – misalignment of physical and imagined egocentric reference frame). May’s explanation has been adopted in models of spatial cognition, such as Avraamides and Kelly (2008).

The empirical evidence in spatial cognition literature seems to “push” towards the occurrence of two representational systems involved in spatial processing to explain the amount of findings effectively. Therefore, on the next pages the most relevant models accounting for multiple representational systems will be briefly discussed (For an extensive review, I suggest Avraamides & Kelly, 2008).

The two–system self–reference model proposed by Sholl (2001; Easton & Sholl, 1995) postulates the existence of an allocentric system – storing object–to–object spatial relations in long term memory with no preferred orientation – and an egocentric (self–reference) system – storing self–to–object spatial relations according to two body axes as a reference frame. According to the author, the egocentric system is responsible for the communication with the allocentric system to retrieve information from long term memory; therefore, to report the position of an object from an imagined perspective, people have to superimpose the egocentric reference system on the object position, encoded in the allocentric system, in order to adequately align the two orientations.

Wang and Spelke (2000) claimed the existence of three systems. Firstly, an egocentric system stores spatial relations between the observer and each of the relevant objects in the immediate environment, updating them on the basis of object–to–objects relations. Secondly, an enduring allocentric system stores the geometric configuration of the environment with no spatial relations. Thirdly, a subsystem stores perspective dependent visual information.

Similar to Sholl (2001), Mou, McNamara, Valiquette, and Rump (2004) posited that processing spatial information involves two representational systems. The egocentric system stores transient self–to–objects spatial relations and updates them as the observer is moving; moreover, the authors claimed that this system decays rapidly without perceptual cues, especially from vision. The allocentric system however, maintains stable object–to–object relations in long term memory; in addition, representations in the allocentric system are not orientation–free, since they are stored with a preferred direction (McNamara, 2003).

The two–system model by Waller and Hodgson (2006) presents some aspects in common with the models of Sholl (2001) and Mou et al. (2004). Indeed, the model proposed the existence of two systems which seem to work simultaneously, coding spatial information from the surroundings. The spatial relations are stored in a transient egocentric system with high precision but decay rapidly in absence of perceptual cues. However, the egocentric system remains active when non visual information (e.g., idiothetic information) is available, highlighting the importance of idiothetic cues in this model. Indeed, idiothetic cues, together with visual ones, support the continuous spatial updating in the egocentric system, allowing the active interaction with the surroundings. This system is sustained by an enduring system, in which spatial relations are maintained in a prolonged but coarser manner.

Finally, the model proposed by Avraamides and Kelly (2008) interpreted the empirical results, which emerged in spatial updating studies, according to May's (2004) interference hypothesis. Indeed, the authors claimed the existence of two separate systems – an egocentric sensorimotor system coding the self–to–objects relations for the main objects in the environment, and an allocentric system – which may interact. In particular, the autonomous activation of the sensorimotor system seems to interfere with the allocentric system when reasoning in the immediate environment occurs.

When examining the models featuring multiple systems, it is evident that all described models, although with some exceptions and slight differences, proposed one system of processing self–to–objects relations and another system of dealing with object–to–object relations. Therefore, it seems the existence of (at least) two systems responsible for the processing and maintenance of spatial information is well established in spatial literature. Moreover, in the described models, physical movement at the time of retrieval of spatial relations, namely the time of testing, fulfils an important role in spatial updating, since it seems to align the egocentric reference system with the required imagined orientation; or to link the egocentric reference system to the allocentric representation in the case of a remote environment. Therefore, it seems that physical movement, acting on the egocentric system, is tightly connected to a well established effect in spatial updating, namely the sensorimotor alignment effect.

### 6.3 Alignment effects: encoding and sensorimotor

The term alignment effect refers to the ease of reasoning about spatial relations from perspectives that are aligned, rather than misaligned, with the relevant reference frames. Empirical evidence has shown two main kinds of alignment effects: memory (or encoding) and sensorimotor (Kelly et al., 2007). These alignment effects have commonly been associated with the organizational structure of spatial memory and with spatial updating respectively, and have been considered as the manifestation of the type of reference frame adopted during the storing and retrieval of spatial information.

The encoding alignment effect refers to the ease in reasoning from a perspective that is aligned with the encoding perspective, that is, the perspective from which the spatial information was encoded. This effect has been confirmed by many studies, demonstrating that retrieving spatial information is easier from a perspective adopted when learning the environment (Shelton & McNamara, 1997). Thus, spatial information seems to be stored in a preferred direction, which in some situations corresponds to the reference frame selected through the egocentric experience. Moreover, the encoding alignment effect is consistent with previously discussed allocentric systems, and in particular with those maintaining enduring object–to–object relations in an orientation dependent manner (Mou et al., 2004).

The sensorimotor alignment effect refers to the ease in reasoning from a perspective that is aligned with the actual facing perspective, that is, the perspective from which locations are observed at that specific moment. This effect determines the ability of people to encode self–to–object relations, thanks to a spatial representation which continuously updates these relations while moving. The sensorimotor alignment effect is facilitated by imagery instructions (that is, instructions to mentally visualize the environment and the imagined movement) and by physical movement, which seem to encourage the link between the two representational systems (Hatzipanayioti, Galati, & Avraamides, 2015; Kelly et al., 2007).

# Chapter 7
# The role of physical movement in described environments

The supportive role of physical movement is well–established in spatial updating literature in both immediate and remote environments. However, I have not yet addressed the contribution of movement within environments verbally presented. In the previous sections, it has been discussed how verbal descriptions of an environment are able to generate a spatial mental model which contains the features and spatial relations of the described environment. In order to explain whether and how physical movement affects spatial reasoning in described environments, it is necessary to introduce some crucial assumptions derived from the embodied cognition approach.

## 7.1 Action-grounded language: linguistic meaning approaches

Two main approaches to the meaning of linguistic material have been described: a symbolist and an embodiment approach. According to the symbolic approach, language meaning is conveyed by the activation of mental symbols in our mind through words and sentences. Indeed, abstract and amodal symbols, such as words, should be translated into internal meaningful symbols, such as mental models (e.g., Burgess & Lund, 1997; Chomsky, 1980). However, this approach encounters some concerns in the light of studies demonstrating that abstract symbols – that is, words – need to be grounded in the real world to be completely understood (Shapiro, 2008); conversely, if abstract symbols continue to refer to other abstract symbols, they lack a meaningful key (see Chinese room, Searle, 1980; Harnad, 1990).

The embodiment approach assumes that the meaning of language is grounded in bodily activities (e.g., Barsalou, 1999; Glenberg & Robertson, 1999, 2000; Stanfield & Zwaan, 2001). Thus, it seems that the experiences involved in the real world activate perceptual, motor and even emotional neural mechanisms and that these same mechanisms are also activated during the processing of language (Sadosky & Paivio, 2001). The indexical hypothesis (Glenberg & Robertson, 1999, 2000) suggests that meaning is based on actions, since it originates in the biomechanical features of the body and perceptual systems (Glenberg, 1997). Thus language becomes meaningful through a three-way process of transformation in which people cognitively simulate the actions described in the texts.

## 7.2 Action-grounded language: empirical evidence

A common method employed to assess the indexical hypothesis is by evaluating the statistical interaction – i.e. action-sentence compatibility effect (ACE) – between the action implicitly implied by a sentence and the action required to perform it. Participants are exposed to a sentence implicitly describing an action in a specific direction (e.g., towards the body) and are asked to respond by performing a matching (e.g., towards the body) or a non-matching (e.g., away from the body) action. By using this paradigm, Glenberg and Kaschak (2002) found a significant interaction between the implied action of a sentence and the executed action (meaning-action effect) for sentences describing both concrete and abstract actions. Subsequently, the meaning-action effect has been extended to abstract sentences, such as counterfactual phrases and metaphors (de Vega & Urrutia, 2011; Santana & de Vega, 2011). Moreover, past studies reveal that grounding language about abstract (or difficult) content was employed by both professional scientists (Ochs, Gonzales, & Jacoby, 1996) and high school students (Roth 1999), when they tried to understand difficult topics.

These findings were used by Zwaan (2004) as evidence in support of his theory, the Immersed Experience Framework (IEF), proposing that words activate corresponding experiences. In particular, the author claimed that when reading a sentence, people construct a perceptual simulation of the described situation, becoming therefore "immersed experiencers" of that situation.

The embodiment approach has gained empirical confirmation from several studies employing behavioral paradigms. Indeed, similar to Glenberg and Kaschak, other researchers reported a meaning-action matching interaction resulting in faster response times than a non-matching interaction (Borreggine & Kaschak, 2006; Zwaan & Taylor, 2006). However, other studies did not reveal a facilitation but a negative interference for similar meaning-action matching interactions (Buccino et al., 2005; de Vega, Moreno, & Castillo, 2011). The negative interference means that the same implicit actions described in the sentences impair the corresponding motor responses. By manipulating the temporal delay between the comprehension phase and the physical response, it has been demonstrated that a negative interference occurred when the sentence and the response were temporally close (< 200ms). Conversely, the positive interference occurs for longer delays (> 200ms); this outcome has been interpreted as the result of a neural competition for the same resources.

The embodiment approach has received confirmation from a great number of studies in the domain of neurophysiology and cognitive neuroscience. Indeed, it has been observed that the same cerebral areas are activated for a word and its experienced referent. Moreover, several neuronal mechanisms seem to account for the embodiment effects, such as motor resonance (Fisher & Zwaan, 2008), Hebbian assemblies (Pulvermuller, 2008) and mirror neurons (Rizzolati & Arbib, 1998).

According to de Vega (2012), this approach would have functional advantages, for example by facilitating the interaction with physical events and communication between people. As for the physical events, grounding meaning in actions strengthens people's connection with the world, preparing them to act in response to physical events. Regarding communication, embodied meaning seems to improve communication among people, since all individuals use the same perceptual-motor mechanism to construct shared representations. Moreover, it is noteworthy that people construct mental imagery of the items described that overlaps the conceptual meaning developed during language comprehension (e.g., Yaxley & Zwaan, 2007). Thus, it seems that people employ perceptual and conceptual representations of objects and actions to direct language comprehension (see Fischer & Zwaan, 2008).

In summary, understanding linguistic meaning by activating perceptual and motor experiences of a verbal referent seems to be effective in supporting people during the processing of multiple daily activities. In addition to what has just been discussed, the embodiment approach is extremely important for reasoning about narratives. Narratives are fictitious stories describing the actions, thoughts and features of a protagonist and the environmental situation in which the story takes place. According to the embodiment approach, readers should "immerse" themselves in the story to better understand the meaning of the text; indeed, some studies report that participants internally adopt (embody) the perspective of the protagonist and mentally simulate her/his described movements and actions (e.g., Bower & Morrow, 1990; Zwaan & Rapp, 2006; Rapp, Klug & Taylor, 2006). Therefore, in the light of embodied cognition, the role of physical movement in narratives will be discussed in the next chapter.

# Chapter 8
# The role of physical movement in narratives

It is common to learn spatial information about a new environment from texts describing the number and location of relevant landmarks and their spatial relations, because of the ability to represent spatial information effectively in a spatial mental model. In addition, the embodiment approach posits that when reading/listening to a narrative, people imagine themselves "within" the story, perceptually simulating the actions executed by the protagonist by activating their own motor and perceptual experiences. It is therefore licit to wonder whether the same effect found for spatial updating in remote, perceived environments might also occur in remote, described environments. Indeed, in the light of the functional equivalence of verbal descriptions and perceived scenes (Loomis et al., 2002), it is possible to expect that perceived and described environments share the same structural properties, resulting in similar spatial effects.

## 8.1 The influence of the encoding perspective

The processing of spatial information contained in a verbal description of an environment will be extensively discussed in the next pages, focusing principally on the role of physical movements on spatial updating. However, before starting to examine how physical movements affect spatial reasoning in narratives, it is necessary to deal with a well established effect in spatial cognition, namely the influence of the encoding perspective. Although the learning (or encoding) perspective also occurs in the following section, a more inclusive discussion is needed here, as Experiment 4 examines how physical movements affect the preference for the encoding perspective; thus, some empirical outcomes need to be discussed.

Converging findings have suggested that spatial information is maintained in spatial memory in a specific reference frame (e.g., Mou et al., 2004). The adopted reference frame can be selected depending on the relative weight of several factors available during the encoding (Galati & Avraamides, 2013), such as environmental layout and structures (e.g., Mou & McNamara, 2002; Kelly, Avraamides & Giudice, 2011), the learning perspective (e.g., Shelton & McNamara, 2001), or even the instructions given to the participants (Greenauer & Waller, 2008). However, in the absence of other relevant cues, people rely on their learning perspective, that is, they adopt a reference frame aligned with the orientation from which the environment was encoded (Wilson, Wilson, Griffiths, & Fox, 2007; Wilson, Tlauka, & Wildbur, 1999).

This effect has been interpreted claiming that people adopt the reference frame of the learning perspective, because it is easier to interpret and retrieve spatial terms with an egocentric connotation, such as “right” or “left” (Hintzman, O’Dell, & Arndt, 1981). Therefore the adoption of a specific reference frame seems to be related to the perspective employed to encode the described objects. However, this interpretation does not completely clarify where the preference for the learning perspective originates; indeed, the learning perspective is commonly both the first perspective adopted by the protagonist and the perspective from which objects are encoded.

To disentangle this ambiguity, Hatzipanayioti et al. (2015) experimentally separated the first perspective adopted from the encoding perspective. The authors provided participants with a narrative in which the protagonist was described as rotating within the environment before some or all the objects were introduced. In addition, in the last experiments, they manipulated the testing orientation by asking participants to rotate according to the protagonist’s rotation. The results revealed that participants preferred to adopt the first perspective with respect to the encoding perspective. However, when participants were asked to rotate, their performance was better in the encoding perspective, even though the first perspective alignment effect still existed. These findings suggest that the initial reference frame is aligned with the protagonist’s first perspective. Moreover, the physical movements allowed participants to adopt their updated reference frame to encode spatial relations. It is noteworthy that the two reference frames might be co-activated in response to the simultaneous involvement of enduring and transient representational systems.

## 8.2 Physical movement and narratives

According to the embodiment approach, when imagining themselves within the story, readers adopt the perspective of the protagonist (e.g., Bryant, Tversky, & Franklin, 1992) and, as a consequence, they might adopt the reference frame of the protagonist; this new perspective might influence the reference frames involved in the processing of spatial scenes. Avraamides (2003) pointed out that different reference frames may be involved during the processing of perceptual or verbally described scenes. In particular, the author distinguished between an *ecological reference frame* and an *imagined reference frame*. The former typically occurs when processing perceived scenes (and immediate described environments) and encodes object locations relative to the observer’s actual egocentric reference frame; thus, it employs three orthogonal axes centered on the observer’s position to locate objects surrounding the observer (Mou & Mc Namara, 2002). The link with the observer’s actual egocentric position accounts for the assumption that the mental representations derived from such processing may be grounded in the sensorimotor system.

The latter, instead, mainly occurs when processing non-immediate verbally described environments and employs an egocentric reference frame centered on the protagonist's position, which corresponds to the imagined reference frame of the reader. It is noteworthy that such an imagined reference frame is not necessarily overlapping the ecological reference frame at the same time, since the first is bound to the protagonist's position, whereas the latter is bound to the reader's actual position. Therefore, such misalignment might be responsible for potential differences in spatial effects, in particular spatial updating, between remote, perceived and described environments. Moreover, the location of the protagonist is provided by spatial and locative expressions in the narrative, while this occurs automatically in perceived environments. Therefore, it has been suggested that the expressions contained in the text may force participants to adopt, as a framework, a specific orientation determined by particular landmarks (Levelt, 1996).

As stated by Avraamides (2003), the process of updating the protagonist's location in a narrative has been studied by employing two main paradigms. On the one hand, the reading time paradigm requires participants to read a text in which some spatial inconsistencies about the protagonist's location occur; the increased reading time needed to process inconsistent information regarding the position of the protagonist suggested that participants were sensitive to that information (O'Brien & Albrecht, 1992; de Vega, 1995). On the other hand, a recognition task was used by asking participants to evaluate whether some objects were present in previously read stories; the objects were consistent either with the actual or with a former location of the protagonist. Different results emerged by employing this paradigm. Whereas de Vega (1995) reported no difference when responding to objects located in the former or actual protagonist's location, longer response times were found for objects located in the former location when the location was made more salient (Levine & Klin, 2001), suggesting that the accessibility of objects was affected by the protagonist's location.

In addition to these two paradigms, other studies (de Vega, Rodrigo, & Zimmer, 1996) employed pointing direction tasks – that is, physically pointing in the direction of a target object previously described in a story – or labeling direction tasks – that is, verbally naming the direction of a target object previously described in a story. However, pointing and labeling seem to activate different cognitive processes and so involve different reference frames, which might affect spatial updating differently. Thus, de Vega and Rodrigo (2001) examined whether the testing modalities (pointing or labeling) and the types of movement required (physical or imaginary) affected the spatial updating performance. The authors found an effective spatial updating during physical movement, but only with the pointing task. However, some concerns about these results were highlighted by Avraamides (2003), who examined the circumstances supporting spatial updating in described environments by employing a different paradigm (i.e., Spatial Frameworks Paradigm, see Franklin & Tversky, 1990).

In the study by Avraamides (2003), the results showed that participants' performances from the learning perspective, namely the perspective in which they learned the environment, were faster than from the other perspectives. Moreover, the data revealed the occurrence of spatial updating in described environments when some conditions were fulfilled. In particular, it seemed that both physical movements and sensorimotor encoding were necessary for updating egocentric spatial relations effortlessly. As regards sensorimotor encoding, the findings showed that participants relied on their actual egocentric reference frame, which did not support spatial updating, instead of adopting the more appropriate imagined reference frame. Therefore, it might be possible that, even if the texts activate motor representation, they do not engage specific motor programs (de Vega, 2008). These findings are in line with the assumption that people are not able to ignore updating while physically moving (e.g., Farrell & Thomson, 1998), confirming as a consequence the importance of the egocentric frame. Moreover, Avraamides posited that spatial updating can be enhanced by strengthening the weight of the sensorimotor frame – such as by placing visual cues corresponding to the object locations in the testing room.

The involvement of the sensorimotor framework in described environments might also be obtained by enhancing the contribution of physical movements, in particular when the physical movements determine a change in the egocentric perspective of participants. Avraamides et al. (2013b) examined whether a reorientation of participants' perspective affected the retrieval of spatial positions. Across four experiments, they manipulated the movements required by the participants, which were tested in a Judgment of Relative Direction (JRD) task, "Imagine facing x, point to y". As is evident by looking at the experiments, the authors also manipulated the explicit instructions of mentally visualizing the described environment, since it has been suggested that people encode spatial information only (or at least more carefully) when the information is relevant to the task (e.g., Radvansky & Copeland, 2000). Therefore, when reasoning about remote perceived environments, explicit instructions to visualize the environment are necessary for a deliberate spatial updating (Wang, 2004).

Therefore, across the experiments of Avraamides et al. (2013b), the participants were asked *to imagine to rotate* as the protagonist described in the narrative (Exp.1), or *to physically rotate* as the protagonist (Exp. 2), or *to physically rotate* as the protagonist, with the explicit instruction to mentally visualize the described environment (Exp. 3) or finally *to physically rotate in the opposite direction* of the protagonist (Exp. 4). The results revealed that participants did not update protagonist-to-objects relations after imagined movement (Exp.1), nor after physical rotation with and without explicit information (Exp. 2 e 3). Finally, the physical rotation in the opposite direction to that of the protagonist did not determine any sensorimotor interference (Exp. 4). Hence – despite a slight sensorimotor effect found for accuracy in experiment 2, which was not confirmed by Experiment 3 – the evidence suggests that spatial updating in described environments is substantially different from updating in remote environments, since neither physical movement nor explicit instructions proved to be effective in sustaining spatial updating. In addition, the data showed that participants encoded spatial information from the learning perspective in described environments similarly to remote environments (e.g., Kelly et al., 2007), confirming that people rely on their egocentric experience at the time of the encoding to structure their spatial organization.

# Chapter 9

# Experiment 3. The influence of walking on spatial updating of described environments[2]

## 9.1 Introduction

Spatial updating refers to the ability to keep track of the changing self–to–object relations while the observer is moving (Rieser, 1989; Wang & Spelke, 2000). This is a fundamental mechanism in everyday life, since it prevents getting lost while moving within an environment. In spatial cognition literature spatial updating has been thoroughly investigated, commonly using tasks in which participants were asked to learn the location of some targets and then re–localize them from a novel standpoint (Rieser, 1989; Presson & Montello, 1994).

This spatial updating ability has been represented in several models (e.g., Mou, McNamara, Valiquette, & Rump, 2004; Waller & Hodgson, 2006), postulating the existence of two representational systems that work simultaneously: a transient sensorimotor representation, which encodes self–to–object relations and continuously updates them; and an enduring allocentric representation, which maintains object–to–object relations and stores enduring information in a preferred direction. Thus, one's own position can be considered as a link between the two representations, as it is both the origin of sensorimotor representation and a location in the allocentric representation.

The ability to update one's own orientation relative to objects has been typically studied by using spatial updating tasks in immediate environments. However, extending this literature, some studies have focused on spatial updating in imagined remote environments, namely real environments not perceptually accessible in a given moment, but only imagined. In this last situation, it has been demonstrated that spatial updating occurs with the aid of physical movement (Avraamides, Galati, & Papadopoulou, 2013a; Rieser, Garing & Young, 1994), while imagined movement seems to be unable to foster spatial updating. These results could be explained by hypothesizing that movement creates a link between the observer's body and remote environments, which would ground objects in a sensorimotor framework (de Vega & Rodrigo, 2001). Indeed, spatial updating mechanisms would operate only on objects anchored in a sensorimotor system (Avraamides, 2003). According to this framework, the physical movement would influence spatial reasoning in situations that encourage a link between the two

[2] This is an Accepted Manuscript of an article (Walking reduces the gap between encoding and sensorimotor alignment effects in spatial updating of described environments) published by Taylor & Francis in The Quarterly Journal of Experimental Psychology on 23.02.2016, available online: http://wwww.tandfonline.com/10.1080/17470218.2016.1157615.

representations, as movement would anchor remote allocentric representation to the sensory–motor one.

The different features of the two representational systems can account for a well–known effect in spatial cognition, that is, the ease of reasoning from an aligned perspective rather than a misaligned one with a specific reference frame (Kelly, Avraamides, & Loomis, 2007). Furthermore, we can distinguish between two alignment effects: the encoding alignment effect and the sensorimotor alignment effect. The former refers to a better performance when the imagined perspective is aligned with the perspective from which the spatial information was encoded. This effect is consistent both with well–established results in the spatial memory field, demonstrating that spatial information is stored in a preferred direction, and with the previously explained allocentric representation, which maintains enduring object–to–object relations. The sensorimotor alignment effect instead, refers to a better performance when the imagined perspective is aligned with the actual facing perspective, that is, the perspective from which locations are observed at that specific moment. This effect determines the ability of people to encode self–to–object relations, thanks to a spatial representation which continuously updates these relations while moving. The sensorimotor alignment effect does not occur unless a link between the two representational systems is stimulated through physical movement (Hatzipanayioti, Galati, Avraamides, 2015; Kelly et al., 2007).

The aid of movement for spatial updating in imagined remote environments has been hypothesized to occur even in described environments, according to the findings of embodiment studies (Zwaan, 2004). Embodiment theory claims that readers identify themselves as the story's protagonist and imagine themselves within the story (Zwaan & Radvansky, 1998). Consistent with this theory, it has been demonstrated that physical movement congruent with the protagonist's movement can help a reader to update spatial information (Zwaan, 2004).

A recent study investigated the occurrence of spatial updating in described environments (Avraamides, Galati, Pazzaglia, Meneghetti, & Denis, 2013b). The authors focused on spatial relations' updating following a reorientation of the reader, which was performed according to the protagonist's reorientation. What happened was participants read narratives, where the protagonist was described as reorienting 90° to the left or to the right; then participants were asked to rotate on a swivel chair or to imagine the rotation, in line with the protagonist's motion. The authors did not find a sensorimotor alignment effect, neither when participants imagined the rotation nor when they physically rotated. Comparing these results with previous studies, we notice that spatial relations updating in described environments is different from updating in imagined remote environments (see also Avraamides, 2003). Indeed, in described environments physical movement did not support self–to–objects updating as in imagined remote environments, causing the disappearance of the sensorimotor effect even when readers moved according to the narrative. Based on previous literature, the authors expected that vestibular cues and visual flow changes acquired through the swivel chair would provide enough information to allow a perspective reorientation, but according to their results, these cues did not determine the occurrence of the sensorimotor alignment effect (Avraamides et al., 2013b). Thus, it seems that visual and vestibular cues do not provide enough information to successfully foster spatial reorientation in described environments.

In the experiment of Avraamides et al. (2013b), the primary source of information for rotation is vestibular in origin. Therefore, it seems that the vestibular information – which is responsible for the sense of balance and spatial orientation – gained by rotation through the swivel chair is not sufficient for spatial updating in described environments. However, we do not know whether other types of movement, such as active walking, could provide enough information to promote spatial updating in described environments. Indeed, active walking would provide a specific multisensory pattern of information (such as vestibular, proprioceptive and efferent motor information), which might be very different from that deriving from rotation. Specifically, proprioceptive information is provided by sensory feedback coming from the movement of the muscles and joints (Lackner and Di Zio, 2005), whereas efferent motor information derives from movement motor commands originating in the brain (Sperry, 1950; Von Holst and Mittelstaedt, 1950). The combination of vestibular, proprioceptive and efferent motor information is defined as idiothetic information (Chrastil and Warren, 2013). According to Frissen, Campos, Souman and Ernst (2011), passive movement through space provides vestibular – and not proprioceptive – information, walking in place provides proprioceptive and efferent motor – and not vestibular – information, while active walking through space provides all this information at the same time (idiothetic information).

The role of idiothetic cues in everyday life is noteworthy, since it has been demonstrated that the integration of multisensory cues generated by our movement fosters adequate spatial updating (see Jürgens & Becker, 2006; Lafon, Vidal, & Berthoz, 2009), helping people to keep track of objects previously explored (Chrastil & Warren, 2013; Ruddle & Lessels, 2009). Therefore, an active movement experience providing idiothetic cues may create an effective spatial representation, which in turn would lead to improved spatial abilities. Given this framework, it is not surprising that blind people's spatial abilities can be developed by enhancing their experience of independent movement, for example favouring both their motor education in childhood and their motor autonomy in everyday navigation, as suggested by Loomis et al.

(1993), and by Schmidt, Tinti, Fantino, Mammarella, and Cornoldi (2013). Moreover, the same authors suggested the possibility that people's spatial abilities could be more dependent on their independent movement experience than on their visual experience.

Given the importance of the integration of cues generated by our movements on spatial updating, we questioned the influence of walking (not just rotation) on spatial updating within described environments. From previous studies it is not clear whether other types of movements, such as walking, would convey a different multisensory pattern of information compared to rotation, leading to results different from those of Avraamides et al.. Therefore, the present study provides an extension to the outcomes found by Avraamides et al. (2013b), using a similar methodological design and increasing the effect of physical movement by adding one more condition. Indeed, since Avraamides et al. (2013b) found no sensorimotor effect after physical rotation congruent with the protagonist's motion, we aimed to investigate whether different results would emerge when physical walking is involved.

We hypothesized a different contribution of walking on spatial updating, compared to both rotation and imagination of rotation; moreover, we expected a decrease of the gap between encoding and sensorimotor alignment effects. Indeed, it is well established that people maintain spatial information from a preferred perspective, commonly the perspective from which locations are encoded. The existence of the encoding alignment effect has been observed in many studies, confirming the supremacy of the encoding perspective on all other perspectives regarding spatial representation. However, we might assume that the separate representational systems which operate in parallel to solve spatial tasks (for a review, see Avraamides & Kelly, 2008) are somehow related, since some findings suggest that they rely on common resources (Sholl, 2001). As a consequence, the enconding and sensorimotor alignment effects might be not totally independent. Thus, we hypothesized that by increasing the sensorimotor alignment effect through physical movement, the supremacy of the encoding perspective could be reduced.

## 9.2 Method

### Participants

Forty–two university students (13 M; 29 F) participated in this experiment in exchange for academic credits. Their age varied from 19 to 24 years (M = 19.89; SD = 1.45). Four students did not complete the experiment and were excluded from the analysis. All participants signed the informed consent before starting the experiment. Participants were naive as to the purpose of the experiment.

### Material and Apparatus

A notebook connected with headphones Sennheiser HD515 (total harmonic distortion <0.2%) provided participants with auditory information (narrative descriptions and testing trials). The same notebook, running E–Prime 2 Software, was used to generate trials and perform the task.

### Stimuli Description

Six narratives were provided to participants in the experimental sessions; one extra narrative was used only in the practice session. The narratives were constructed according to those used in the experiment performed by Avraamides et al. (2013b), and were comparable in terms of both number of words and reading comprehension difficulties. All the narratives were in Italian and in second person, describing a protagonist waiting in different environments: a classroom, a restaurant kitchen, a boat, a waiting room, a hotel hall and a minimarket. In the practice session a park was described.

The structure of the narratives included ten steps: 1) Brief description of the situation to introduce participants into the story. 2) Description of the geometry of the environment. In all narratives, the environment was described as a square–shaped area with protagonists standing in the middle and facing a fixed direction. 3) Description of the protagonist turning his/her head around to look at the surrounding environment. 4) Description of four objects placed in the environment at canonical directions (namely in front of, at the left of, at the right of, and behind the protagonist) and named “orienting stimuli” (Figure 9.1.). Each object was accompanied by visual details to improve the participants’ imagination of the environment. 5) Explicit instructions that encouraged participants to form a mental image of the described environment with the objects inside. 6) Description – enriched by visual details – of four more objects placed at the corners of the described environment and named “target stimuli”. The objects were introduced either in an egocentric or in an allocentric perspective. 7) Explicit instructions that encouraged participants to form a mental image of the described environment with all of the eight described objects. 8) Protagonist reorientation. Description of the protagonist’s movement, who rotated 90° to the left or to the right and walked towards the object in front of her/him. 9) Explicit instructions that reminded participants to act according to the assigned condition: imagine to rotate, physically rotate, or physically rotate and walk (see the “Experimental Design” section for a detailed explanation). Then, participants were asked to name the object facing the protagonist after the reorientation. l0) Final sentence that concluded the narrative.

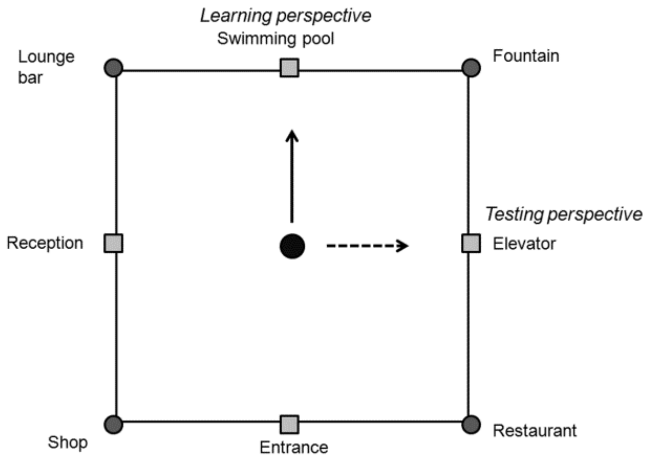


**Figure 9.1** Environment described in the hotel narrative. The continuous arrow represents the learning perspective, while the dotted arrow represents the reoriented perspective after a 90° rotation to the right (testing perspective). Participants in the imagination condition performed the task physically aligned with the swimming pool, whereas in the rotation and walking conditions they performed the task aligned with the elevator.

The narratives were recorded, isolating each step on a different auditory track, to give participants the opportunity to take a break for a few seconds between one step and the next. The description steps, in which the story was described, and the instruction steps, in which instructions were provided to participants (steps 5, 7, 9), were differently recorded: a female voice illustrated the descriptions, while a male one illustrated the instructions. The step–structured recording and the use of different voices aimed to facilitate the comprehension of the narratives.

### Experimental Design

A within–subjects experimental design was employed with two independent variables: Action and Perspective. With regard to Action, participants were exposed to three conditions: Imagination (I), Rotation (R) and Walk (W). The imagination and rotation conditions were designed according to the experimental procedures employed by Avraamides et al. in their study (2013b). Indeed, in the imagination condition, participants were asked just to stand and imagine the rotation of the protagonist of the narrative, while in the rotation condition, participants were asked to stand and physically rotate according to protagonist's movement. To test the influence of physical movement on spatial updating, we introduced a further condition, in which participants were asked to stand, physically rotate and move – namely to walk a few steps – according to the protagonist's movements.

The second independent variable was the Perspective, which refers to the perspective that participants had to mentally adopt during a Judgement of Relative Direction (JRD) task in the testing phase. The JRD task requires to mentally adopt an orientation and to indicate an object from that orientation ("Imagine facing X, point to Y"); thus Perspective is the alignment of an imagined perspective (Imagine facing) with one of three different orientations. Therefore, the Perspective variable is manipulated across three conditions: Learning, Testing, and Opposite–to–Testing conditions. Referring to Figure 9.1, in the learning condition participants had to imagine being oriented with the learning perspective (e.g., imagine facing the swimming pool, point to Y); in the testing condition participants had to imagine being oriented with the testing perspective (e.g., imagine facing the elevator, point to Y); in the opposite–to–testing condition participants had to imagine being oriented with the opposite–to–testing perspective (e.g., imagine facing the reception, point to Y). In other words, Perspective depends on the congruency of the imagined perspective adopted during each trial with: a) the fixed initial orientation used to encode the narrative; or b) the participant's orientation after the reorientation in the narrative, either only imagined in the imagination condition or physically acted out in the remaining conditions; or c) the orientation diametrically opposite to the testing perspective. The fourth perspective (opposite–to–learning) was not considered for the analysis. The Perspective conditions were randomised within the task.

**Procedure**

The experiment took place in a square–shaped area, delimited by wooden panels. Participants were engaged in six different experimental sessions, and listened in each one to a different narrative. Participants performed two experimental sessions for each Action condition. The order of conditions was counterbalanced across the participants (II–RR–WW, II–WW–RR, etc.).

As in Avraamides et al.'s studies (2013b), the experimental sessions included a learning phase, in which participants encoded a narrative and imagined the described environment, and a testing phase, in which participants performed the task. However, differing from Avraamides et al.'s protocol, in the present study we blindfolded the participants and provided the narratives acoustically, in order to eliminate the support of visual cues in the development of the environmental representation. Indeed, in this way we avoided that participants could visually identify environmental cues from the experimental area and consequently use those cues as reference points to anchor the spatial representation[3].

Before starting the experiment, participants performed a practice session; only when they reported that they correctly understood the task the experiment started. After the practice session, participants were blindfolded, accompanied into the experimental area, and positioned standing at a fixed orientation, facing a wall in the area. This position, called “learning perspective”, remained the same for all participants in all conditions. Then participants started the learning phase. They were asked to wear the headphones and listen to a narrative. When participants listened to the steps of the narrative in which the protagonist’s reorientation was described, they were required to act according to the assigned condition (to imagine to rotate; to physically rotate; to physically rotate and walk), and to name the object in front of the protagonist. The direction of the protagonist’s reorientation was alternated across the experimental sessions; the direction of the first reorientation was counterbalanced across the participants. The experimenters controlled the correct execution of participants’ movements, and took note of the objects named by participants. We named the perspective that participants were required to adopt after the reorientation “testing perspective”. The testing perspective could be either mental or physical, and was to be maintained during the testing phase. Indeed, at the end of the narrative, participants started the testing phase without changing their orientation. This means that participants in the imagination condition performed the testing phase in the learning perspective, while participants in the rotation and walk conditions performed the testing phase in the same position they had after their previous reorientation (see Figure 9.1).

The testing phase consisted of 16 randomized trials of judgement of relative directions (imagine facing X, point to Y), in which participants were required to point to a target stimulus – that is, a stimulus placed in a corner – from the imagined perspective of an orienting stimulus – that is, a stimulus placed in a canonical direction. The number of trials was obtained by using all possible combinations of 4 orienting stimuli with 4 target stimuli. Participants were instructed to press a key on the keyboard as soon as they adopted the perspective required by the sentence “imagine facing X”; this response time was called “orientation latency”. After pressing the key, the sentence “point to Y” appeared, and participants were required to indicate the correct direction of Y by pressing one of the four keys (I, M, R, C in a QWERTY keyboard) associated with each direction. Since participants were still blindfolded when performing the task, these

[3] In a recent study on spatial updating by Hatzipanayioti, Galati and Avraamides (2014), it seems that the distribution of the alignment effects is equivalent across two conditions with open and closed eyes, respectively, since no interaction was reported by the authors.

keys were marked with a protruding felt pad to ease their identification by touch. Participants were required to press I to indicate their front–right corner, R for their front–left corner, C for their back–left corner and M for their back–right corner. We measured both response times and accuracy. It is noteworthy that participants were asked to perform the task as accurately as possible, without any explicit requirement regarding response times. At the end of the 16 trials, participants were accompanied outside the experimental area, where they could remove the blindfold and rest before starting the following experimental session.

### 9.3 Data Analysis and Results

Orientation latency, response times and accuracy were considered for data analysis. For response times, the rule of two SDs from the mean was used to identify outliers and exclude them from data analysis. Moreover, as in previous studies (Avraamides & Kelly, 2010; Avraamides et al., 2013b), the collected data was transformed to calculate both the encoding alignment effect and the sensorimotor alignment effect, using the performance on opposite–to–testing condition as a baseline. To obtain the encoding alignment effect for response times, we subtracted the average response times collected in the learning condition from those collected in the opposite–to–testing condition; similarly, to obtain the corresponding sensorimotor alignment effect, we subtracted the average response times collected in the testing condition from those collected in the opposite–to–testing condition. This subtraction was reversed when considering accuracy scores: the average accuracy of the opposite–to–testing condition was subtracted from that of the learning/testing condition to obtain the encoding/sensorimotor alignment effects, respectively. Since the alignment effects derive from these subtractions, higher values correspond to stronger effects. As regards the orientation latency, we did not calculate the corresponding alignment effect, since it was considered only in the preliminary analysis. Alignment (encoding vs. sensorimotor) was used as the independent variable in the statistical analysis. An overview of the results is reported in Table 9.1.

| Action | Perspective | Orientat. latency (ms) | Accuracy (%) | Response times (ms) |
|---|---|---|---|---|
| Imagination | Learning | 2966 (419) | 87 (03) | 2070 (546) |
| | Testing | 3056 (524) | 77 (05) | 2653 (782) |
| | Opposite | 3176 (518) | 78 (05) | 2711 (908) |
| | | | | |
| Rotation | Learning | 3060 (510) | 87 (03) | 2204 (626) |
| | Testing | 3129 (706) | 79 (04) | 2458 (780) |
| | Opposite | 3054 (506) | 76 (05) | 2701 (899) |
| | | | | |
| Walk | Learning | 3174 (565) | 84 (04) | 2327 (609) |
| | Testing | 3144 (572) | 75 (05) | 2259 (653) |
| | Opposite | 3106 (519) | 73 (06) | 2551 (704) |

**Table 9.1** Mean orientation latency, accuracy, and response times for each Perspective in each Action condition. Standard errors are reported in parentheses.

*Orientation latency*

As a preliminary analysis, we performed a 3 x 3 (Perspective x Action) repeated measures ANOVA on orientation latency. The results did not reveal any significant effect, suggesting that the time required to adopt the imagined perspective did not change depending on conditions.

*Accuracy*

As regards accuracy, a 3 x 3 (Perspective x Action) repeated measures ANOVA revealed a significant main effect for Perspective, $F(2, 72) = 8.491$; $p < .001$; $\eta^2 = .191$, while neither Action main effect nor interaction were statistically significant. Thus, we calculated planned contrasts, showing that participants were more accurate in the learning condition than in both the testing ($p = .005$) and opposite–to–testing ($p = .003$) conditions, while no difference was found between the testing and opposite–to–testing conditions.

A 2 x 3 (Alignment x Action) repeated measures ANOVA was performed for accuracy. Similarly to previous results, we found a significant main effect for Alignment, $F(1, 38) = 9.851$; $p = .003$; $\eta^2 = .206$, and no effect for Action and interaction. Then, we compared the two alignment effects, revealing that participants were more accurate when aligned with the learning perspective than with the testing perspective ($p = .003$).

*Response times*

As concerns response times, a 3 x 3 (Perspective x Action) repeated measures ANOVA showed a significant main effect for Perspective, $F(2, 46) = 36.219$; $p < .001$; $\eta^2 = .612$, and a significant interaction, $F(4, 92) = 6.637$; $p < .001$; $\eta^2 = .224$. Similarly, a 2 x 3 (Alignment x Action) repeated measures ANOVA revealed a significant main effect for Alignment, $F(1, 25) = 18.777$; $p < .001$; $\eta^2 = .429$, and a significant interaction, $F(2, 50) = 17.520$; $p < .00$; $\eta^2 = .412$ (see Figure 9.2 and 9.3). Given that both interactions were statistically significant, we separately examined how Perspective and Alignment varied within each Action condition. It is particularly important to focus on each Action condition to make our results more comparable with those of Avraamides et al. (2013b).

*Imagination condition.* We ran a one–way ANOVA for Perspective, considering response times as a dependent variable. The analysis revealed a significant main effect, $F(2, 58) = 21.705$; $p < .001$; $\eta^2 = .428$, and planned contrasts revealed that participants were faster to respond in the learning condition than in both the testing ($p < .001$) and opposite–to–testing conditions ($p < .001$), while no difference was found between them. As regards Alignment, we performed two one–sample t–tests, which revealed the existence of an encoding alignment effect, $t(31) = 5.582$; $p < .001$; $d = 1.39$, but no sensorimotor alignment effect. A paired–sample t–test confirmed a significant difference between them, $t(31) = 5.921$; $p < .001$; $d = 0.98$.

*Rotation condition.* We performed the same analysis as in the imagination condition, and obtained similar results. The main effect for Perspective was significant, $F(2, 62) = 12.439$; $p < .001$; $\eta^2 = .286$, and performances were faster in the learning condition than in the testing ($p = .01$) and opposite–to–testing ($p < .001$) conditions. However, performances in the testing condition were faster than those in the opposite–to–testing condition ($p < .001$). One–sample t–tests revealed significant values for both encoding, $t(34) = 4.216$; $p < .001$; $d = 1.01$, and sensorimotor, $t(33) = 3.937$; $p < .001$; $d = 0.95$, alignment effects. However, the encoding alignment effect remained higher than the sensorimotor alignment effect, $t(33) = 2.935$; $p<.01$; $d = 0.47$.

*Walking condition.* Applying the same analysis as in the previous conditions, we found a significant main effect for Perspective, $F(2, 54) = 6.388$; $p <.005$; $\eta^2 = .191$, but planned contrasts did not reveal a statistical difference for response times between learning and testing conditions. Conversely, participants in the opposite–to–testing condition performed slower than in both the learning ($p < .01$) and testing conditions ($p < .001$). Moreover, both encoding, $t(30) = 3.138$; $p < .005$; $d = 0.80$, and sensorimotor, $t(29) = 4.579$; $p < .001$; $d = 1.18$, alignment effects were above the chance level. However, they did not differ from each other as in the previous conditions.

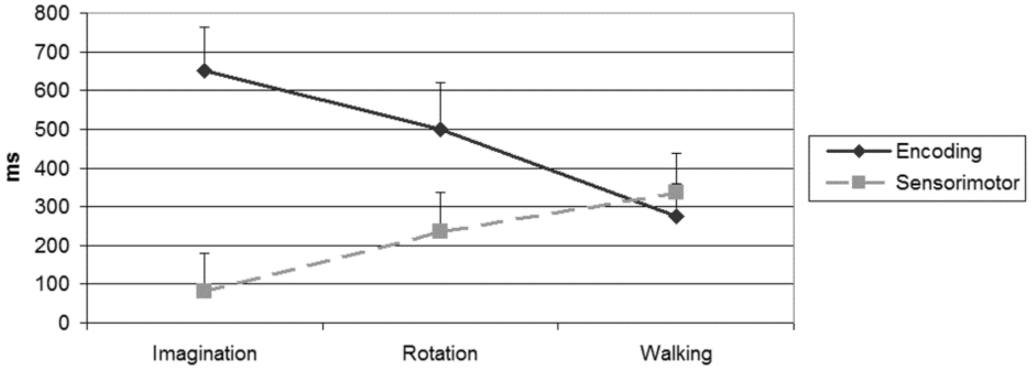


**Figure 9.2** Encoding and sensorimotor alignment effects in imagination condition, rotation condition and walking condition. Bars show positive standard errors.

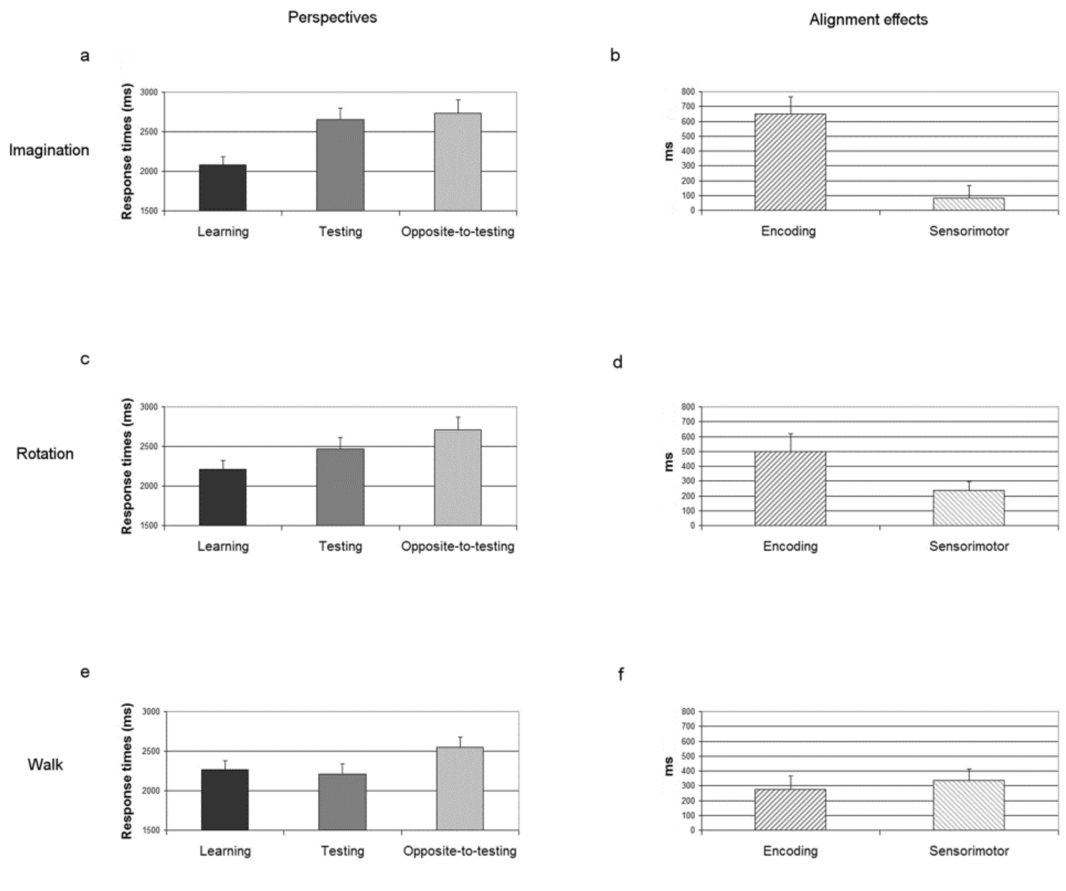


**Figure 9.3** Perspective and alignment effects for response times in imagination condition (a, b), rotation condition (c, d) and walking condition (e, f). Bars show positive standard errors. As for alignment effects, higher values corresponded to greater effects.

### 9.4 Discussion

The aim of the present study was to investigate the influence of walking on spatial updating within described environments. We hypothesized a different contribution of walking on spatial updating compared to both rotation and imagination of rotation. Moreover, we expected a decrease of the gap between encoding and sensorimotor alignment effects in the walking condition. The results confirmed our hypotheses.

The preliminary analysis showed no difference between the conditions regarding orientation times, suggesting that the time needed to re–orientate is not influenced by Action conditions. As regards accuracy scores, our results are in line with previous findings (Mou et al., 2004), showing a better performance when participants reason from a perspective aligned with the learning perspective, compared to other perspectives. Action had no effect on accuracy, indicating that movement does not mitigate the influence of the learning perspective on accuracy. The absence of the effect of Action on accuracy might be due to the instructions given to participants. Indeed, participants were encouraged to focus on the accuracy of their responses, ignoring other aspects of performance, such as response times. The remarkable attention of participants on accuracy resulted in a ceiling effect, since all participants reached high accuracy scores (average accuracy ranged from 89% to 73%, see Table 9.1).

We therefore expected more interesting findings from the analysis of response times, as participants were required to focus only on accuracy and consequently did not consciously control the time required for their responses. As regards alignment effects, the most interesting results are the findings that emerged in the walking condition, showing both encoding and sensorimotor alignment effects, but no difference between them. The results from the imagination condition however are consistent with those of Avraamides et al. (2013b), showing a significant encoding alignment effect, but no sensorimotor effect. In the rotation condition, in contrast to Avraamides et al., we found both an encoding and sensorimotor alignment effect; even though the encoding alignment effect was higher than the sensorimotor one.

It may appear surprising to find such a difference regarding the benefits provided by rotation in ours' and in Avraamides et al.'s study. However, we should consider that there are three factors that may have caused this difference: the narrative encoding modality, the active rotation vs rotation through a swivel chair, and the visual access during the trials. Our experimental protocol partially differed from that of Avraamides et al. since we asked participants to listen to the narrative and not to read it on a display monitor. Moreover, our participants were asked to rotate when standing instead of sitting in a swivel chair. Finally, our participants were blindfolded during the whole experiment and this could have influenced participants' attention, enhancing the effect of rotation. However, a recent study by Hatzipanayioti, Galati and Avraamides (2014) demonstrated that participants performed better with open than with closed eyes in a similar spatial updating study. Further research should investigate these hypotheses, examining whether executing the experimental session with open eyes would determine a different pattern of results. However, we believe that the difference derives from the specific action required from participants; indeed our participants executed an active rotation whereas participants in the other study performed a relatively passive rotation (because of  the swivel chair). Results seem to suggest that idiothetic cues might be gained also by active rotation, affecting therefore the spatial updating and leading to the occurrence of the sensorimotor effect.

As regards Perspective, in imagination and rotation experiments Avraamides et al. (2013b) found faster responses for trials in which the participants' perspective was aligned with the learning perspective, compared to both testing and opposite–to–testing perspectives. Our results of the imagination and rotation conditions substantially replicated their findings. Moreover, in the walking condition we were able to eliminate the gap between the learning and testing conditions, since in both conditions participants performed equally fast.

The evidence found in the walking condition seems to confirm our hypothesis regarding the reduction of the gap between the encoding and sensorimotor alignment effects; moreover, the results revealed that the difference between the learning and testing conditions was similarly eliminated in the walking condition. We might interpret these results as an effect of the specific multisensory pattern of information gained by walking, which seems to inversely affect the ease of reasoning from the learning and the testing perspectives; in effect, the ease of reasoning from the learning perspective decreased, whereas the ease of reasoning from the learning perspective increased. This effect of walking is particularly evident in the alignment effects, as previously shown in Figure 3. By observing the figure, it appears that the decrease of the encoding effect corresponds to the increase of the sensorimotor effect, suggesting that the two alignment effects may be somehow related. However, this hypothesis would contrast with the assumption of other researchers (Kelly et al., 2007; Avraamides & Kelly, 2010) claiming the independence of the two alignment effects. Further studies are necessary to shed light on this issue.

The results of the present experiment suggest that walking provides a different multisensory pattern of information which influences the creation of a spatial representation of described environments. Walking seems to support the sensorimotor effect, determining the updating of self–to–objects relations. According to the outcomes found in the rotation and walking conditions, the described environments seem to be comparable to the imagined remote environments regarding spatial updating, when participants' experience is corroborated by a movement that provides an idiothetic contribution. Indeed, previous studies demonstrated that information derived from rotation through a swivel chair enhanced spatial updating in remote environments, but not in described environments. Probably, information derived from rotation through a swivel chair is not sufficient to support spatial updating in described environments. Conversely, in our experimental conditions (active rotation and walking) we augmented information derived from movement, and this enriched information was probably sufficient to support spatial updating even in described environments.

The results of the current study are in line with those of recent research by Hatzipanayioti, Galati and Avraamides (2014), in which physical walk was required during the learning phase. The experimental procedure was similar to that of Avraamides et al. (2013b), but participants were asked to walk in the laboratory according to the protagonist's movements during the description of the environment. This physical walk provided participants with even stronger idiothetic information, since movement accompanied the encoding of spatial relations within the narratives. The authors found a significant sensorimotor effect with extensive walking executed during the encoding of the environment, consistent with the idea that strong idiothetic information gained by walking is sufficient to foster spatial updating even in described environments.

From a theoretical perspective, the multisensory patterns of information acquired by walking (and active rotation) could be the factor that strengthens the link between allocentric and sensorimotor representations, anchoring the described objects in the sensorimotor framework (de Vega & Rodrigo, 2001) and consequently favouring the spatial updating process. Vice versa, we can suppose that the information provided by rotation through a swivel chair in described environments is not strong enough to connect the two representation systems. In this case the contribution of the sensorimotor system cannot be integrated with allocentric representation, preventing spatial updating.

The present outcomes are in line with the theoretical framework of embodiment, since our data further demonstrate that physical movement congruent with a protagonist's movement can help the reader in updating spatial information (Zwaan, 2004). Moreover, comparing our results with those presented in literature, it is possible to notice that movement has a key role in this framework: the more the protagonist is moving in the environment, the more the reader is intrinsically involved in the story, and the more the reader is able to correctly represent the environment and to easily interact with it. However, further research is needed to investigate this topic.

Further research is also required to better understand which walking components mostly provide the information useful for spatial updating. Indeed, we can consider the walking required by our participants as a combination of rotation and translation, which affects spatial representation and navigational tasks differently (Ruddle & Lessels, 2009). Future studies should investigate the effects of translation and rotation separately, moreover considering the effect of the combination of physical and imagined movements; new conditions, such as “imagine rotation and walk forward” or “rotate and imagine walking forward”, should be considered.

In conclusion, our study aimed to investigate the role of walking in spatial updating within described environments. Our data suggest that walking provides a different multisensory pattern of information compared to physical rotation, reducing the gap between the encoding and sensorimotor alignment effects. We explained these results in terms of an enhanced link between allocentric and sensorimotor representations, promoted by the multisensory pattern of information acquired through walking. This explanation highlights an important methodological issue that should be considered in future studies. Whereas previous research considered the contribution of physical movement without providing further specifications, our study indicates that it is imprecise to refer to physical movement when considering only rotation, since we demonstrated that walking and rotation provide different information, which in turn determines different impacts on spatial updating.

# Chapter 10

# Experiment 4. The influence of walking during the encoding of described environments[4]

## 10.1 Introduction

The ability to maintain spatial relations between the self and the surrounding objects and the possibility to constantly monitor the changing relations during movement are essential to guarantee adequate daily navigation. Indeed, these abilities prevent people from getting lost, allow them to re–orient and ease the identification of the right way or reference landmarks. In spatial cognition literature, spatial updating exactly refers to the ability to keep track of the changing self–to–object relations when moving (Rieser, 1989; Wang & Spelke, 2000).

According to the model by Mou et al. (2004), spatial updating seems to be supported by the architecture of spatial representation, which involves two different representational systems: an enduring allocentric and a transient sensorimotor system.

The enduring allocentric system maintains the enduring object–to–object relations and remains stable during movement. Indeed, the spatial information retained in memory is contained in an allocentric framework, where it is not possible to perform online information updating. This system accounts for the preference of reasoning from a specific perspective, which usually is the learning perspective. The empirical evidence actually suggests that a specific allocentric reference frame is selected from the environmental cues to store the information accordingly; in absence of relevant landmarks, people adopt the perspective from which they have encoded the environment as the reference frame, determining the preference for the learning perspective (Wilson et al., 2007). In spatial cognition literature, the ease of reasoning from the learning perspective compared to other perspectives is named encoding alignment effect (Kelly et al., 2007).

The sensorimotor egocentric system stores self–to–object information and updates online changing egocentric relations when the observer is moving inside the environment, without a considerable effort. According to the model of Mou et al. (2004), spatial updating occurs only in immediate environments, since self–to–object relations are maintained and updated only in the sensorimotor system. When spatial updating occurs, the sensorimotor alignment effect – that is,

[4] This is a manuscript (Walking during the encoding of described environments enhances a perspective-independent spatial representation) submitted to The Quarterly Journal of Experimental Psychology (Taylor & Francis) on February 2016 and it is currently under evaluation for possible publication.

the ease of reasoning from a perspective that is aligned with the observer's actual perspective – emerges (Kelly et al., 2007).

The updating of egocentric relations occurs online and without cognitive effort in the immediate environments, since the observer completely relies on the sensorimotor system. However, it has been demonstrated that people are able to update egocentric relations also in environments not directly perceived, namely remote environments. In this case, several studies agreed in claiming that spatial updating occurs with the aid of physical movement, while imagined movement seems to be unable to foster spatial updating (e.g., Avraamides et al., 2013a; Rieser et al., 1994).

In the domain of described environments, namely environments linguistically described and not previously experienced, only a few studies investigated the occurrence of spatial updating (e.g., Rieser et al., 1994; Avraamides, 2003; Avraamides et al., 2013b). Only some of them suggested that people were able to update egocentric relations within narratives, and physical movement seemed to be a crucial factor (Hatzipanayioti, Galati, & Avraamides, 2014; Santoro, Murgia, Sors & Agostini, 2016). The idea that spatial updating can also occur in described environments is supported by evidence suggesting that verbal descriptions are functionally equivalent to perceptual experience concerning the cognitive spatial representation produced (Lyion & Gunzelmann, 2011; Loomis, Klatzky, Avraamides, Lippa & Golledge, 2007). Furthermore, embodied cognition suggests that the reader could be so engaged in the story to totally impersonate the protagonist; indeed several studies confirmed the ease of performing actions consistent with the protagonist ones and the difficulty of performing actions in opposition to the protagonist (Zwaan, 2004; Zwaan & Radvansky, 1998). Thus, if the reader imagines to be the protagonist, then s/he will act in the sensorimotor system, determining the occurrence of spatial updating within described environments.

Among the studies that investigated spatial updating in described environments, only few focused specifically on the effect of walking (Hatzipanayioti et al., 2014; Santoro et al., 2016). In a recent study (Santoro et al., 2016) blindfolded participants were provided with a narrative describing an environment with eight objects inside and asked to mentally imagine the environment described, according to Avraamides et al.'s procedure (2013b). Then the protagonist of the narrative was described as turning 90° to the right or to the left; according to the assigned condition, participants were asked to remain still and imagine the rotation, to physically rotate or to physically rotate and walk a few steps. The results suggest that physical movement, and in particular walking, fosters spatial updating within described environments. This evidence has been explained as a consequence of the different patterns of information obtained by rotation and by walking. Moreover, it has been suggested that the multisensory pattern of vestibular, proprioceptive and efferent motor information (hereafter, idiothetic information) obtained by walking can reduce the “supremacy” of the learning perspective compared to the other perspectives.

It is noteworthy that the movements, either imagined or physically performed, involved in the previously described studies occurred only after the encoding of the environment, since movements were executed only during the protagonist’s reorientation. Thus, when participants performed the movements, they had already encoded the environment with the described objects and then the information derived from movements could minimally affect the spatial representation.

Based on previous evidence in literature, we wondered whether physical movement performed simultaneously with the encoding of the environment would affect spatial updating even more. A recent study by Hatzipanayioti et al. (2014, Experiment 3) partially answered our question. The authors examined whether extensive physical movements enhanced spatial updating during the encoding of described environments, determining the occurrence of the sensorimotor alignment effect. The authors asked participants to reproduce the protagonist’s movements by walking into the room as they read the narrative, and found both an encoding and a sensorimotor alignment effect. Unfortunately, they did not totally disentangle the question, since they did not systematically manipulate the effect of walking during the encoding of the environment.

To better clarify this aspect, we investigated whether allowing participants to walk simultaneously with the protagonist’s movements both during environment encoding and reorientation, would affect spatial updating differently, compared to participants only walking during the protagonist’s reorientation. We expected a higher sensorimotor effect for the participants who also walked during the description of the environment (encoding + reorientation) compared to those participants who only walked after the description (reorientation), as a consequence of enhanced spatial updating.

Thus, the present study aimed to investigate whether and how participants could benefit from the execution of physical movement during the encoding of described environments, in terms of enhanced spatial updating.

## 10.2 Method

### Participants

Fifty–six university students (13 M; 43 F) participated in this experiment in exchange for academic credits. Their age varied from 18 to 30 years (M = 19.7; SD = 1.6). All participants signed the informed consent before starting the experiment. The participants were naive regarding the purpose of the experiment.

### Experimental design

We employed an experimental design with two independent variables: Action (between subjects) and Perspective (within subjects). With regard to Action, participants were randomly assigned to two conditions: Standing (S) and Walking (W). During the encoding of the narratives, in the Standing condition, participants were simply asked to stand facing a fixed direction; in the Walking condition, participants were asked to walk through the experimental area, according to the protagonist's movements.

As in previous studies (e.g., Avraamides et el., 2013b; Santoro et al., 2016), the second independent variable was the Perspective, which refers to the perspective which participants had to mentally adopt during a Judgement of Relative Direction (JRD) task during the testing phase. The JRD task required to mentally adopt an orientation and to indicate an object from that orientation ("Imagine facing X, point to Y"); thus the Perspective is the alignment of an imagined perspective (Imagine facing) with one of three different orientations. Therefore, the Perspective variable was manipulated across three conditions: Learning, Testing, and Opposite–to–Testing. In the Learning condition participants had to imagine to be oriented with the learning perspective; in the Testing condition participants had to imagine to be oriented with the testing perspective; in the Opposite–to–testing condition participants had to imagine to be oriented with the opposite–to–testing perspective. The three conditions were randomized within the task.

### Material and apparatus

To provide participants with auditory information (narrative descriptions and testing trials) we employed a notebook connected with headphones Sennheiser HD515. The same notebook, running E–Prime 2 Software, was used to generate trials and perform the task.

### Stimuli description

Two narratives were provided to participants for the experimental sessions; another narrative was used only in the practice session. The narratives were constructed according to those used in previous studies (Avraamides et al., 2013b; Santoro et al., 2016), and were comparable in terms of both number of words and reading comprehension difficulties. All the narratives were in Italian and in the second person. They described a protagonist waiting in two different environments: a classroom and a minimarket. A park was described in the practice session. Since we manipulated the access to the idiothetic information during the encoding of the narratives, we created two slightly different versions for each narrative, in order to make participants more comfortable when moving through the experimental area. A previous pilot test revealed no differences between the two versions of the narratives, in terms of both reading comprehension and encoding difficulty.

In the Standing condition, the narratives were structured as in previous studies. The narratives included an initial description of the geometry of the environment, which was a square–shaped area with the protagonist standing in the middle and facing a fixed direction. Then, four objects – named "orienting stimuli" – located at the canonical directions (namely in front of, at the left of, at the right of, and behind the protagonist) were introduced and the participants were asked to visualize the objects inside the environment. Four more objects – named "target stimuli" – located at the corners of the square–shaped area were then described, and the participants were again asked to form a mental image of the described environment with all eight objects. The objects were introduced either in an egocentric or in an allocentric perspective. After the description of the environment, the protagonist was described as rotating 90° to the left or to the right and walking towards the object in front of her/him (protagonist's reorientation). A following explicit instruction reminded participants to move according to the protagonist's movement and to name the object they faced after reorientation.

In the Walking condition, similarly to Hatzipanayioti et al. (2014), we adapted the order of the presentation of the objects to match the description with the requests of the condition, namely walking while listening to the narrative. Therefore, the environment was described in a clockwise direction, and the protagonist was introduced to one object at a time and walked towards it. The location of the objects was the same as in the Standing condition and the objects were again introduced either in an egocentric or in an allocentric perspective. Participants were asked to walk a few steps according to the protagonist's movements. After the introduction of the first four objects, the participants were asked to visualize the environment with the described objects. Then, the description of the remaining four objects started and the participants were asked again to visualize the environment with all eight objects. The protagonist's reorientation and the instruction to move according to the protagonist's movements were the same as in the Standing condition.

As in our previous study (Santoro et al., 2016), the narratives were constituted of several steps, each of which was isolated in a different auditory track; moreover, a female voice illustrated the descriptions of the environment while a male one illustrated the explicit instructions provided to the participants. These two characteristics aimed to facilitate the comprehension of the narratives.

**Procedure**

The experiment took place in a square–shaped area, delimited by wooden panels. Each participant was randomly assigned to one of the two Action conditions (either Standing or Walking). The experiment consisted of two experimental sessions, in which participants performed the same task with two different narratives (classroom and minimarket).

As in the previous studies (Avraamides et al., 2013b; Hatzipanayioti et al., 2014; Santoro et al., 2016), the experimental sessions included a learning phase, in which the participants were exposed to a narrative and asked to imagine the described environment, and a testing phase, in which participants performed a Judgement of Relative Direction (JRD) task. Whereas Hatzipanayioty et al. (2014) manipulated the visual access during the task, in the present study we decided to blindfold all the participants and to provide the narratives acoustically, since we wanted to eliminate the support of visual cues in the development of the environment representation.

Before starting the experiment, participants performed a practice session. They were exposed to the description of a park and then performed 16 JRD trials. Only when participants claimed to have correctly understood the task, the experimental procedure started. Thus, participants were blindfolded and accompanied into the experimental area, where they were positioned standing in the middle of the area, facing a wall in a fixed direction, called "learning perspective".

The learning phase started by asking participants to wear the headphones and to listen to the narrative, which included the description of the environment and the protagonist's reorientation. The requests to the participants in the learning phase partially differed for the two Action conditions. Indeed, during the description of the environment, in the Standing condition, participants were required to stand still, while in the Walking condition, participants were required to continuously walk a few steps, imitating the movements of the protagonist. In both conditions, when the protagonist's reorientation occurred, the participants were asked to rotate and walk a few steps according to the protagonist's movements. After the reorientation, the participants were asked to name the object that the protagonist was actually facing, in order to monitor an adequate comprehension of the described environment. The experimenter controlled for the correct execution of the movements required and took note of the object's name. At the end of the narrative, the participants started the testing phase without changing their orientation; this meant that they performed the task in the same position they had after the reorientation.

The testing phase was the same for both Action conditions and was designed in accordance with previous studies (Avraamides et al., 2013b; Hatzipanayioti et al., 2014). The participants were asked to perform 16 trials of the JRD task (imagine facing X, point to Y), which consisted in pointing to a target stimulus – that is, a stimulus placed in a corner – from the imagined perspective of an orienting stimulus – that is, a stimulus placed in a canonical direction. After listening to the sentence "imagine facing X", the participants were asked to press a key on the keyboard as soon as they imagined the required orientation; this response time was called "orientation latency". Then, the sentence "point to Y" started and participants were required to press one of four keys (I, M, C, R in a QWERTY keyboard) associated with each direction, in order to indicate the correct direction of Y. The four keys were marked with a protruding felt pad to ease their identification by touch, since participants were blindfolded when they performed the task. We measured both accuracy and response times, although we asked the participants to perform the task as accurately as possible, without explicitly mentioning the response times. At the end of the 16 trials, the participants were accompanied outside the experimental area and allowed to remove the blindfold and rest before the following experimental session with the second narrative started.

### 10.3 Data Analysis and Results

Accuracy, orientation latency and response times were considered for the data analysis. For both orientation latency and response times the rule of two standard deviations from the mean was applied to identify the outliers and eliminate them from the data analysis. For response times, we analyzed only the data from the trials correctly performed. Data collected were transformed into alignment effects as suggested by Avraamides and Kelly (2010) and Avraamides et al. (2013b). In particular, both encoding and sensorimotor alignment effects were calculated for all the dependent variables, using the opposite–to–testing condition as a baseline. Indeed, as regards accuracy, the mean score obtained in the opposite–to–testing condition was subtracted from the mean score obtained in the learning/testing condition, in order to find the encoding/sensorimotor alignment effects, respectively. The formula was reversed to calculate the alignment effects for the orientation latency and response times: the mean score of the learning/testing condition was subtracted from the opposite–to–testing condition to find the encoding/sensorimotor alignment effects, respectively. Alignment (encoding vs. sensorimotor) was used as an independent variable in the statistical analyses.

*Orientation latency*

As regards the orientation latency, we performed a 3 x 2 (Perspective x Action) repeated measures ANOVA and a 2 x 2 (Alignment x Action) repeated measures ANOVA. Both analyses did not reveal any significant effect, confirming that the time required to adopt the imagined perspective does not depend on the action previously performed.

*Accuracy*

A 3 x 2 (Perspective x Action) repeated measures ANOVA revealed a statistically significant interaction, $F(2,110) = 5.594$; $p = .005$; $\eta^2 = .092$, but no significant main effect. Thus, we calculated the planned contrasts with the Bonferroni correction, showing that in the Learning condition participants were more accurate in the Standing than in the Walking condition ($p = .001$), while no difference between Standing and Walking emerged in the other Perspective conditions. Moreover, the planned contrasts revealed that in the Standing condition accuracy was affected by Perspective: in the Learning condition accuracy was higher than in the Testing ($p = .013$) and Opposite–to–testing conditions ($p = .002$). Conversely, no difference emerged among perspectives in the Walking condition. However, statistics revealed no difference in the overall accuracy score for the two Action conditions.

As regards Alignment, we performed two one–sample t–tests, revealing the existence of an encoding alignment effect in the Standing condition, $t(28) = 3.277$; $p = .003$; $d = 1.238$, but not in the Walking condition, whereas no sensorimotor effect was found for the two Action conditions. Similar to the Perspective analysis, we performed a 2 x 2 (Alignment x Action) repeated measures ANOVA. We found a statistically significant interaction, $F(1,55) = 9.358$; $p = .003$; $\eta^2 = .145$, but no significant main effect. Thus, we calculated planned contrasts to better investigate the direction of the interaction; the results showed a higher encoding effect in the Standing than in the Walking condition ($p = .012$), while no difference emerged for the sensorimotor effect between the two Action conditions.

*Response times*

As in the previous analysis, we performed a 3 x 2 (Perspective x Action) repeated measures ANOVA, and found a significant main effect for Perspective, $F(2,108) = 13.578$; $p < .001$; $\eta^2 =.201$, but no significant values for the interaction and for the Action main effect. Planned contrasts within Perspective revealed that participants performed faster in the Testing condition than in both the Learning ($p < .05$) and Opposite–to–testing conditions ($p < .000$), and faster in the Learning than in the Opposite–to–testing condition ($p < .007$).

As regards Alignment, we performed two one–sample t–tests for each Action condition. The analysis for the Standing condition revealed the existence of a sensorimotor alignment effect, $t(27) = 3.237$; $p < .003$; $d = 1.246$. The encoding alignment effect seemed to be marginally significant, $t(27) = 1.731$; $p = .095$; $d = 0.666$, however it reached a significant value ($p < .05$) considering one single tail, based on previous studies (Hatzipanayioti et al., 2014). Similarly, in the Walking condition, we found both the encoding, $t(27) = 2.195$; $p < .05$; $d = .844$, and the sensorimotor, $t(27) = 3.821$; $p = .001$; $d = 1.47$, alignment effects. Finally, a 2 x 2 (Alignment x Action) repeated measures ANOVA showed only a significant main effect for Alignment, $F(1,54) = 6.273$; $p = .015$; $\eta^2 = .104$, with higher values for the sensorimotor than the encoding alignment effect, and no significant values for the interaction and for the Action main effect.

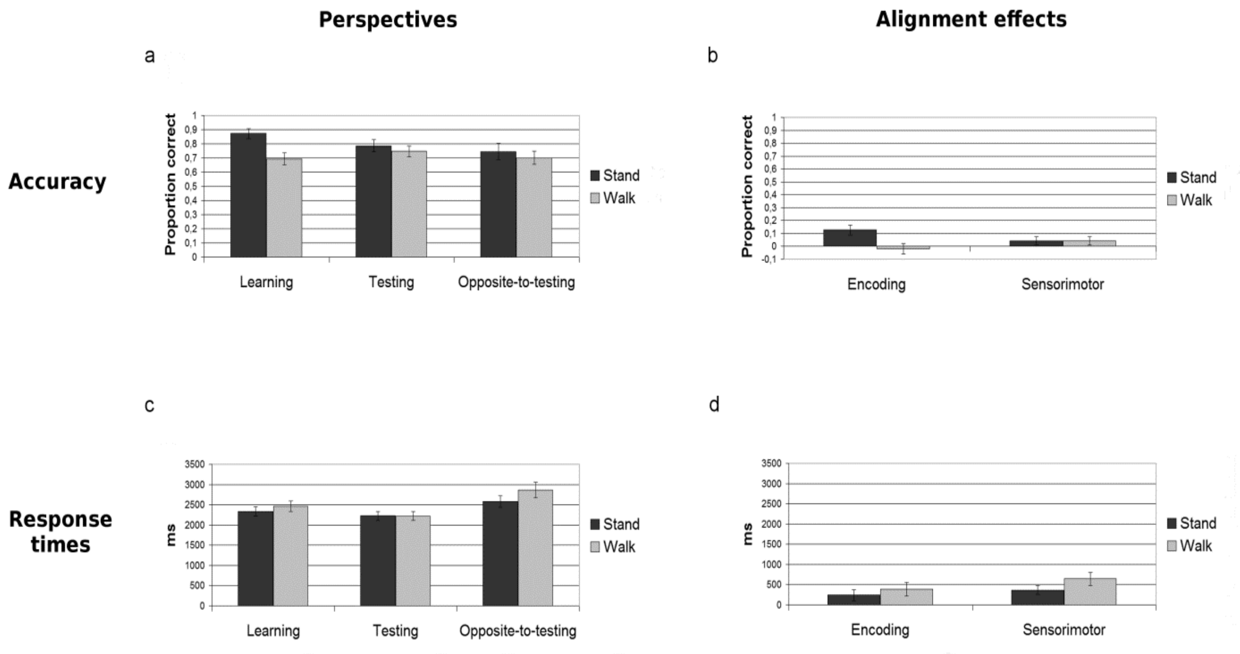


**Figure 10.1** Perspective and alignment effects for accuracy scores (a, b) and response times (c, d) in Standing and Walking conditions. Bars show standard errors. As for alignment effects, higher values correspond to greater effects.

## 10.4 Discussion

The aim of the present study was to investigate whether and how participants could benefit from the execution of physical movement during the encoding of described environments. In particular, we expected an effect of physical movement on spatial updating, hypothesizing a higher sensorimotor effect for participants who walked both during and after the description of the environment compared to those who walked only after the description.

Overall, the results did not support the hypothesis of a higher sensorimotor effect in the Walking than in the Standing condition, however we found a different distribution of accuracy scores across the Perspectives interesting, depending on the physical movement.

The physical movement executed during the encoding of the environment seemed to affect the distribution of accuracy scores differently across the perspectives compared to the movement executed only during reorientation. Indeed, in the Standing condition participants were more accurate in the Learning condition than in the other Perspective conditions, whereas in the Walking condition participants performed equally well in all Perspective conditions. This evidence seemed even clearer when considering the alignment effects: the data showed only a significant encoding effect in the Standing but not in the Walking condition. These outcomes suggest that walking during the encoding of the environment negatively affects the preference of reasoning from the learning perspective. Moreover, we found a lack of the sensorimotor effect in both Action conditions, rejecting the hypothesis of a possible higher sensorimotor effect in the Walking condition as opposed to a higher encoding effect in the Standing condition. Taken together, these results might suggest that walking during the encoding of the environment reduces the preference for reasoning from the learning perspective, favoring instead a global representation, not limited to a specific perspective. Indeed, the reduction of the preference for the learning perspective does not entail a decline of the overall performance, since the absence of the main effect for the Action condition demonstrated that the overall performance did not differ between the two Action conditions.

As regards response times, the physical movement executed during the encoding of the environment seemed not to determine an increase of the sensorimotor alignment effect compared to movement executed only during the reorientation. Indeed, the data showed that participants were faster in reasoning from the testing perspective than from the other perspectives, irrespective of the Action condition; similarly, we found the existence of the sensorimotor alignment effect in both Action conditions. The presence of the sensorimotor effect in both Action conditions could be due to the influence of the idiothetic information gained by walking during the experimental session (during either the protagonist's reorientation or both encoding and reorientation), supporting previous studies which showed a fostering effect of physical movement on spatial updating. The results obtained in the Walking condition for response times are consistent with those found by Hatzipanayioti et al. (2014) showing the occurrence of the sensorimotor alignment effect.

Overall, the concurrent examination of both response times and accuracy scores provided us with a further point of view on our data (see Figure 10.1). In particular, the distribution of response times across the Perspective conditions seemed not to be related to the physical movements executed. Conversely, the distribution of accuracy scores seemed to significantly change depending on the action executed: whereas in the Standing condition participants performed significantly better in the Learning condition than in the other conditions, this pattern of response did not emerge in the Walking condition, where no difference was found across the perspectives. According to the well established idea that response times are related to the cognitive demands required to complete a task, based on the distribution of our results it is reasonable to hypothesize that, with a comparable cognitive effort, participants' accuracy is differently distributed across the perspectives depending on Action.

The different distribution of accuracy scores across the perspectives could be due to the influence of walking on the preference for reasoning from the Learning perspective. In the field of spatial cognition in narratives, a preference for the first perspective described, typically the learning perspective, has been reported in several studies (e.g., Avraamides et al., 2013b; Franklin & Tversky, 1990). However, recent evidence suggests that the participants were partially able to flexibly select the perspective to be adopted. In particular, it seems that the information provided by physical movements may facilitate the adoption of different perspectives other than the learning one (Hatzipanayioti et al., 2015). Our data from the Walking condition seem to be in line with this assumption. Indeed, the continuous change of perspective due to the protagonist's movements avoided participants establishing a fixed reference frame aligned with a specific perspective, allowing them to adopt different perspectives other than the learning one.

The flexibility of spatial representation associated with participants' movements was postulated by Simons and Wang (1998), who claimed that people are able to flexibly adjust or update their spatial representations to achieve a perspective–independent representation, when enough information is available through participants' movements. This might be due to the integration of multiple perspectives obtained from participants' walking, as suggested by Rieser (1989). Our results on accuracy are consistent with these assumptions, indeed walking during encoding seemed to facilitate a perspective–independent representation. It is interesting to note that we did not find an actual facilitation for the other perspectives – that is, an increase of accuracy for the testing and/or opposite–to–testing perspectives – but rather a decreased performance in the learning perspective. This evidence was even clearer when observing the alignment effects: the reduction of the encoding effect was not accompanied by a concurrent increase of the sensorimotor effect. The independence of the alignment effects have previously been suggested by Kelly et al., (2007) and Avraamides and Kelly (2010), even though there is apparently contradictory evidence on this topic (Santoro et al., 2016).

The present outcomes contribute to a better understanding of the role of walking in spatial updating, leaving however important questions unanswered. Therefore, further studies should examine why walking during encoding is not actually sufficient to promote a higher sensorimotor effect than walking only after reorientation. A possible explanation of this result could be the nature of the experimental procedure during encoding, which might not be adequate to increase spatial updating: in particular it could be too cognitively demanding for the participants or, conversely, it could provide not enough information. Further research is needed to better investigate this hypothesis as well as others.

In conclusion, the present study provides new evidence regarding the effect of walking during the encoding of described environments on spatial representation. The main result suggests that physical movement during the encoding of described environments affects the distribution of participants' accuracy scores across the perspectives. In particular, it seems that physical movement during encoding reduces the anchoring for a preferred perspective in favor of a global representation, supporting the development of a perspective–independent representation of described environments.

# Chapter 11

# Experiment 5. The influence of encoding modalities on spatial navigation

## 11.1 Introduction

In daily life, people commonly learn new environments and new routes through a combination of different sources of information. It has been suggested that the perception of the landmark location within an environment generally improves with the number of sensory channels involved (Jürgens & Becker, 2006). Human sensory channels provide different kinds of information – such as auditory, visual and body–based – useful for the development of an adequate spatial representation. However, people seem to rely mainly on sight to locate objects within the environment and to update their position when moving, becoming aware of other sensory cues when deprived of vision. In that situation the contribution of both remaining internal sensory cues (e.g. body–based information) and external symbolic cues (e.g. language) emerges.

Body–based information refers to the information derived from one’s own movement within an environment and usually includes vestibular, proprioceptive and efferent motor information (e.g., Iosa et al., 2012; Frissen et al., 2011; Waller et al., 2004). The role of body–based information has been extensively investigated by using navigational and way–finding tasks, requiring participants to move within an environment in order to reach a targeted location. However, to ease the experimental procedure and to manipulate the different components of body–based information separately, several studies within a virtual environment have been run, providing controversial results.

Ruddle and Lessels (2009) employed a navigational task within a virtual environment to examine the contribution of body–based information on spatial learning and navigation. They found that participants who had full body–based information showed a better performance than those that had visual cues only; moreover their performance was similar to that reported in tasks executed in the real world (Lessels & Ruddle, 2005). The authors also noticed that walking prevented participants to collide with obstacles within the environment explored. Thus, it seems that body–based information helps people to keep track of the explored location; in particular podokinethic cues seem to be responsible for the learning of the environmental layout and consequently, spatial exploration (Chrastil & Warren, 2013), resulting this to be the primary component of active survey learning.

Conversely, different results emerged in the study carried out by Giudice, Bakdash, Legge and Roy (2010). Their findings suggest that body–based information does not significantly influence participants' wayfinding performance, that is, the ability to plan and execute routes (Giudice et al., 2010). This failure could be attributed to the unavailability of body–based feedback during the virtual environment navigation, which is available during real navigation (Giudice et al., 2010). It is noteworthy that studies involving virtual environments commonly employ large environmental spaces to test their participants; therefore, we do not know whether different results would emerge if people were tested in real environments and if different scale environments, such as a room–sized space, would be employed.

The importance of body–based information has been established when reasoning about spatial descriptions. The tight connection between linguistically provided information and cues deriving from body motion has been widely debated (e.g., Zwaan, 2004; Avraamides et al., 2013b), suggesting that physical movement might have a critical role in fostering the development of a spatial representation from verbal information (Giudice et al., 2010). Moreover, it has been demonstrated that full body–based information gained by walking is effective in enhancing spatial updating within spatial descriptions (Santoro et al., 2016 – Exp. 3) and in reducing bias for the encoding perspective (Exp. 4).

Spatial descriptions provide information about the locations of landmarks and their spatial relation by using a linguistic text in which information is contained. The ability to form adequate spatial representations from the verbal descriptions of an environment is supported by empirical evidence. Moreover, it has been demonstrated that a spatial representation built from a verbal description is not only adequate, but functionally equivalent to the spatial representation derived from a visual experience (e.g., Giudice, Bakdash, & Legge, 2007; Loomis et al., 2002). Thus, a spatial representation built from a verbal description maintains a structural coherence with a perceptual–based representation (Afonso et al., 2010).

In summary, previous evidence indicates that physical movements and spatial descriptions are two factors which provide important spatial information. On the one hand, physical movement seems to be effective in supporting navigation tasks (Lafon, Vidal, & Berthoz, 2009), thus, movement experience is considered an important source of information for building an adequate spatial representation of an environment (Picinali, Afonso, Denis, & Katz, 2014). On the other hand, a growing amount of empirical evidence indicates that spatial descriptions guide the construction of effective spatial mental models (e.g., Cocude et al., 1999; Denis et al., 1995; Bestgen & Dupont, 2003). Surprisingly, there is a lack of evidence regarding the effects of physical movements and spatial descriptions on human spatial navigation within real room–size environments. In particular, to the best of our knowledge, there is no study comparing the effects of these two factors.

In order to better understand the role of cues providing spatial information, we aim to examine whether the encoding through spatial descriptions and physical movements affect spatial navigation differently within a real room–size environment. Since the navigation task strongly involves body–based information, we expect better performances for participants who encode the environment through physical movement than for those who encode it through a spatial description.

## 11.2 Method

### Participants

Forty university students (M = 10; F = 30) were recruited for this experiment in exchange of academic credits. Their age varied from 18 to 27 years (M = 19.8; SD = 1.4). All participants signed the informed consent before starting the experiment. Participants were naive as to the purpose of the experiment.

### Material and apparatus

The experiment took place in a square–shape area (4 x 4 meters), delimited by wooden panels. This area represented a fictitious room which had to be encoded by participants. The floor of the area was marked by colored strips to monitor participants' position during the experiment. In particular, the position of seven fictitious objects was marked by 50 x 50 cm squares, according to Figure 11.1. Moreover, a video camera was employed to record the experiment.

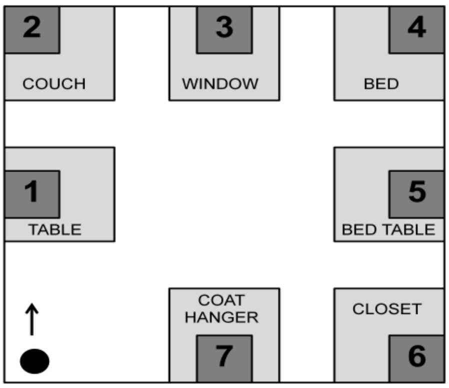


**Figure 11.1** The graphical representation of the environment described. The black dot represents the starting point (and the initial position of the participants); the dark grey areas represent the object locations (2 points); the light grey areas represent the object surroundings (1 point).

## Experimental design

We employed an experimental design with two independent variables, namely, the Encoding modality and the Object position. The Encoding modality variable was manipulated between subjects and refers to the modality through which participants encoded the environment. Participants were randomly assigned to one of two conditions: Description or Walking. In the Description condition, participants were asked to listen to the description of a fictitious room being still at the entrance, whereas in the Walking condition participants were asked to continuously walk in a clockwise direction in order to explore the fictitious room. The Object variable refers to each location to be encoded in the environment.

## Procedure

The experiment included a learning phase, in which participants encoded the fictitious room, and a testing phase in which participants performed a free navigation task.

*Learning phase.* Before starting the experiment, the participants were blindfolded and accompanied into the experimental area. They were positioned at the starting point (i.e. the entrance), which was located at the left back corner of the room (see Figure 1). All participants were provided with a brief introduction about the environment containing a general description of the room (shape and size) and of the objects (number and location): *"you are at the entrance, which is located in the left back corner of the room; inside the room there are eight objects, four of which are positioned at the corners, and four in the middle of the walls"*. The participants were reassured that they would find no object inside the room, but they were asked to imagine the objects as being actually present in the room. The introduction was the same for both groups of participants, but the encoding of the objects differed for the two conditions.

The participants assigned to the Description condition were provided with a spatial description which explicitly illustrated the location of the objects inside the room. When listening to the description, the participants were still at the entrance. The objects were introduced referring to the participants' own position, in a clockwise direction, specifying whether the objects were located in the middle of the wall or in the corner. Thus, referring to Figure 1, participants were first introduced to the object located in the middle of the wall at their left (desk), then they were introduced to the object in the corner (armchair), and so on. The description of the environment took about 50 seconds.

The participants assigned to the Walking condition were not provided with any spatial description. They were asked to explore the room by walking around the perimeter in a clockwise direction, while accompanied by an experimenter. As soon as they arrived at the fictitious location of an object, the experimenter informed them they had reached the position of that specific object (e.g. "*you have reached the desk*"). The exploration ended when participants returned to the starting point. The exploration of the environment took about the same time as for the Description condition.

*Testing phase.* The testing phase was the same for the participants assigned to both conditions. Participants were asked to perform a free navigation task, requiring to physically reach a specific position inside the room from the same starting point (i.e. from the entrance). In particular, participants were required to perform seven trials; each of them consisted of reaching the location of a different object previously encoded. Since participants were still blindfolded, at the end of each trial the experimenter accompanied the participants back to the starting point.

We measured both the time required to reach the object location and the accuracy of the performance. As regards the latter dependent variable, by looking at the grid on the floor, we assigned two points to trials in which participants got the precise location of the object, and one point when they got into the surrounding area (colored by black and grey respectively, in Figure 1). As regards the response times, we measured the time between the end of the trial request (i.e., reach object X) and the moment in which participants declared they reached the object. These data were extracted from the recordings performed during the experiment.

## 11.3 Data Analysis and Results

We calculated the average accuracy values and response times for each Object in the Walking and Description conditions. As for the response times, only the trials correctly performed were included in the analysis.

As regards the accuracy scores, a 2 x 7 (Encoding x Object) repeated measures ANOVA was performed, revealing a significant main effect for Encoding $F(1,38) = 13.861$; $p < .001$; $\eta^2 = .267$, and for Object, $F(6,228) = 3.944$; $p < .005$; $\eta^2 = .094$. No significant interaction was found (Figure 11.2).

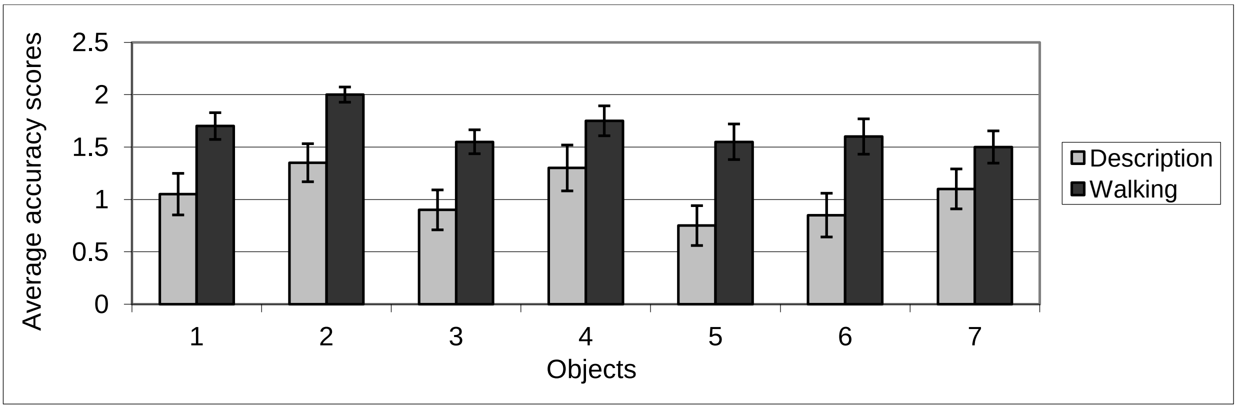


**Figure 11.2** The distribution of the accuracy scores across the object position for each Encoding condition. Bars show standard errors.

Similarly, a 2 x 7 (Encoding x Object) repeated measures ANOVA was performed for response times. In this case the results revealed only a significant main effect of Object, $F(6,132) = 16.692$; $p < .001$; $\eta^2 = .431$, while no significant main effect for Encoding, nor for the interaction was found (Figure 11.3).

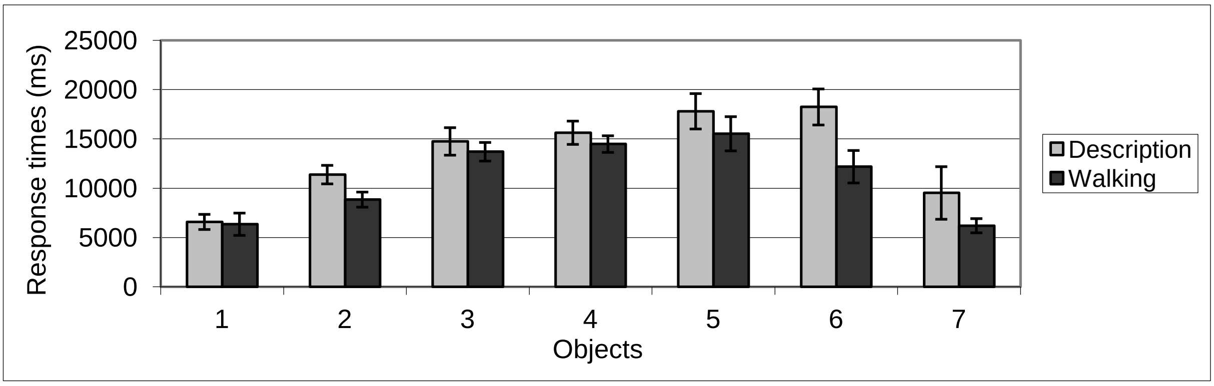


**Figure 11.3** The distribution of response times across the object position for each Encoding condition. Bars show standard errors.

## 11.4 Discussion

In the present study, we aimed to investigate the effects of encoding through spatial descriptions and physical movements on spatial navigation within a real room–sized environment, in order to compare the effects of two encoding modalities which were previously investigated only separately in similar domains (e.g., Giudice et al., 2010; Chrastil & Warren, 2013). We hypothesized a better performance for participants who physically explored the room compared to those who listened to the description, and the results mainly confirmed our expectations.

The results on accuracy scores revealed a significant better performance for the participants who encoded the room through physical movement, compared to those who encoded it through spatial description. Therefore, it seems that the active exploration of an environment during encoding is an effective modality for spatial navigation within the same environment (e.g., Ruddle & Lessels, 2009). Conversely, the mere verbal description of an environment does not seem equally effective in the same task.

The different results obtained with the two encoding modalities can be explained in terms of both information encoding and retrieval. Indeed, it is possible that body–based information obtained by walking enhances the encoding of the environment and consequently spatial representation (see also Exp. 4), thus leading to higher accuracy scores in the navigation task (Ruddle & Lessels, 2009). Alternatively, the different results might be explained in terms of congruency between encoding and testing modalities (see also Exp. 2), as walking during encoding requires physical movement as well as the navigation task. According to the latter interpretation, it could be posit that the better performance of participants who encoded the room through walking, compared to those who encoded it through spatial description, might be due to the direct overlapping of the actions executed during the encoding and testing. However, it is noteworthy that in many cases during the testing phase, participants executed routes different from those executed during the encoding (e.g., diverting the walking direction). Thus, we can exclude that in the testing phase participants merely repeated the actions they had encoded.

Another result revealed by the analyses on accuracy scores is the significant main effect for the position of the objects. We analyzed the scores obtained for each object, since we wanted to examine whether the location of each object within the fictitious room could affect navigation performance differently, depending on the Encoding conditions. However, no significant interaction emerged, suggesting that the performance for participants in the Encoding conditions is not influenced by the position of the target. Indeed, looking at Figure 11.2, it appears that the difference between the participants who encoded the room by walking and through the description is quite stable across all target positions. We did not further examine the main effect of the objects, since we were not interested in this effect itself, but only in its interaction with the encoding modalities.

As regards response times, a difference between the encoding conditions seems to appear for each object in Figure 11.2, however statistical analyses revealed that participants who encoded the room by walking were equally fast in reaching the target objects as those who encoded it through the description. Conversely, a significant main effect for the object position emerged, suggesting that some objects were reached faster than others. However, it is licit to assume that the time needed to reach an object partially depended on its position: objects closer to the starting point were reached faster than those more distant (Figure 11.2b). Similarly, the analyses on accuracy scores revealed no significant interaction, indicating that the average response times did not change across the encoding conditions.

The lack of statistical significance of the encoding modality for response times could be due to the specific characteristics of the experimental procedures, such as the size of the room or the location of the objects. Differently from previous studies, which used environmental spaces (e.g., Lessels & Ruddle, 2005; Waller & Greenauer, 2007), in our procedure the objects were at most 2 meters distant from each other and it is possible that such a distance was not enough to determine an effect for response times. Therefore, future studies should examine whether different results would emerge by manipulating the distances between the targets, and consequently the dimension of the room.

From an applied perspective, our results provide interesting suggestions regarding the way in which people learn a new room–sized environment when sight–deprived. When visually impaired people have to learn the layout of a room (for example, a hotel room), in order to successfully navigate within it, they usually encode the information by listening to verbal descriptions which are provided by a sighted observer. This learning strategy seems to have undeniable "technical" advantages, such as the possibility to listen to the description off–line before experiencing the environment, or to communicate with several individuals at the same time. However, our results suggest that encoding the environment through physical movement is more effective in supporting active navigation than verbal descriptions. Even though further studies are necessary to confirm the occurrence of similar results by testing visually impaired people, it might be possible to improve the experience for visually impaired people within a new environment by allowing them to explore it freely.

In conclusion, while previous studies investigated the effects of physical movement (e.g., Chrastil & Warren, 2013) and verbal descriptions separately (e.g., Giudice et al., 2010), in the present study we compared them. We demonstrated that learning a real room–size environment by actively walking within it is more effective than mere verbal descriptions of the environmental layout for spatial navigation. Our results are in line with previous studies which indicate the importance of physical movement to guide spatial navigation and to support the development of spatial abilities (e.g., Schmidt et al., 2013; Ungar et al., 1996). In our opinion, body–based cues obtained during walking play a critical role in fostering spatial navigation within a room–sized environment and the beneficial effects of these cues should lead to a stronger consideration of physical movement as an effective environmental learning strategy.

# Chapter 12
# Conclusions

## 12.1 General discussion

The aim of the present work was to provide new empirical evidence in the domain of spatial cognition, investigating the influence of spatial descriptions and physical movements on the construction of spatial representations. Therefore, across five experiments we examined different aspects related both to the nature and the characteristics of spatial descriptions (Experiment 1 and 2) and to the influence of physical movements in supporting spatial updating (Experiment 3 and 4) and navigation (Experiment 5).

In Experiment 1 we demonstrated that the occurrence of the serial position effect is affected by the context in which items are presented. By employing verbal stimuli, different accuracy distributions across the item positions emerged as a function of the context provided. In particular, the lack of the serial position effect in favour of stable high–level accuracy scores was found, when the items were described in a spatial description. Hence, it seems that spatial descriptions behave like visuospatial stimuli, even though they actually belong to the verbal domain, released from the constraints of linguistic texts. This result confirmed the effectiveness of employing spatial descriptions to provide spatial information and encouraged us in examining the characteristics of spatial descriptions.

In Experiment 2 we focused on a specific characteristic of spatial descriptions, that is, the encoding direction. Our data indicate that spatial representation is not affected by the direction from which information is encoded and retrieved, whereas reasoning in the spatial representation is facilitated by the congruency between the direction of encoding and retrieval. Hence, the principle of internal consistency seems to be valid even in verbally described environments, indicating that people construct spatial mental models that are coherent with the characteristics of the spatial descriptions.

In Experiments 3 and 4 we examined the occurrence of a well established effect in spatial cognition, namely spatial updating, in described environments. In particular, across the two experiments we manipulated the physical movements executed during the testing (Experiment 3) and during the encoding (Experiment 4) of the described environment. We demonstrated that active physical movements, such as walking during the testing phase, played a critical role to support the updating of spatial relations in narratives, and we interpreted this result in terms of an enhanced link between the sensorimotor and encoding systems. Conversely, when the active physical movements occurred simultaneously with the encoding of the environment, they supported the construction of a perspective–independent spatial representation, reducing the bias for the learning perspective.

Finally, in Experiment 5 we demonstrated that the encoding of a real room sized environment through active walking enhanced the ability to successfully navigate in the explored environment. Thus, even though the spatial description of an environment is adequate in providing spatial information, it seems that walking is more effective when active physical movement is subsequently required.

In summary, the aim of the present work was to shed light on the role of physical movement to support the verbal descriptions of an environment on spatial processes, such as spatial learning, updating and navigation. The theoretical background provided an interpretative framework for our empirical results, which reveal the effectiveness of adopting verbal material to describe an environment, and highlight the important role of physical movement in enhancing people's ability to successfully interact with the described environment. Indeed, we provided new evidence supporting the assumption that spatial descriptions (e.g., Noordzij & Postma, 2005) and physical movements (e.g., Golledge & Spector, 1978) are useful aspects in the construction of spatial representations. On the one hand, the verbal descriptions of an environment seem to be encoded similarly to spatial stimuli, determining the development of a spatial mental model that is structurally coherent with the described environment. On the other hand, the physical exploration of an environment supports people in subsequent spatial navigation, due to the involvement of idiothetic cues. Moreover, when descriptions and movements are joint together, they contribute to reasoning about spatial relations positively, improving spatial updating and supporting the adoption of a perspective independent point of view. Therefore, it seems that people can employ these cues as additional support to face daily activities requiring spatial abilities.

## 12.2 Theoretical perspectives

The experiments discussed in the first part of the present work, dealing with the features of verbal descriptions of environments, can be considered as "precursors" for the subsequent part. In particular, the evidence found in Experiment 1 represents the *conditio sine qua non* to examine the contribution of spatial descriptions on spatial reasoning. Indeed, it is reasonable to investigate the role of physical movement in described environments only after empirical confirmation of the effectiveness of spatial texts to support the construction of accurate spatial representations. Thus, whereas the first part acts like an introduction, the theoretical core of the present work is represented by the second part, which focused on the influence of physical movements in described environments on spatial processes, and in particular on spatial updating. Consequently, in our opinion, Experiments 3 and 4 provide the most relevant findings from a theoretical perspective.

The most important models accounting for spatial cognition, and in particular for spatial updating (e.g., Mou et al., 2004; Waller & Hodgson, 2006), proposed the existence of two representational systems – namely, sensorimotor and allocentric representation – which seem to work simultaneously. In particular, the former is responsible for the encoding and updating of self–to–object relations, while the latter deals with enduring object–to–object relations. Within this framework, we focused specifically on the interaction between the two representations, which is necessary to tackle certain spatial challenges, for example when spatial reasoning and updating of (perceived or described) remote environments is required. It has been suggested that the physical position of people plays a crucial role, since it is both the origin of sensorimotor representation and a location in the allocentric representation.

The physical position of people seems to relate the sensorimotor and allocentric representations, however it has been demonstrated that such a link is not sufficient to assure the occurrence of spatial effects commonly observed in immediate environments (that is, when such a link is not necessary). Thus, our experiments examined how to facilitate the interaction between the two representations, emphasizing the importance of a body physical position.

Our findings indicate that the multisensory patterns of information acquired by walking (i.e., idiothetic information) is effective in strengthening the link between the allocentric and sensorimotor representations and in anchoring the described objects in the sensorimotor framework (de Vega & Rodrigo, 2001). As a consequence, such a strengthened link seems to support the spatial updating process in described environments. Therefore, the idiothetic cues derived from active movement affect the construction of a spatial representation by influencing the relation between the two representation systems. Thus, it is possible that idiothetic cues determine the temporary overlapping of sensorimotor and allocentric representations; in this way people are able to employ the characteristic features of a sensorimotor representation (i.e., the updating of self–to–objects relations), and transfer them to a completely different background (i.e., within a described remote environment).

Physical movement seems to influence another important aspect in spatial cognition studies, that is, a preference for the learning perspective. We demonstrated that the continuous change of perspective due to the protagonist's movements prevented participants from establishing a fixed reference frame aligned with a specific perspective, allowing them to adopt different perspectives other than the learning one. In addition, to provide an additional source of spatial information, physical movements allow people to integrate multiple spatial perspectives (Rieser, 1989), adjusting or updating their spatial representations flexibly. Thus, it seems that active physical movements during the encoding of a remote environment facilitate the construction of a perspective–independent spatial representation.

The integration of multiple perspectives into a unique perspective–independent spatial representation could be interpreted in the light of the hypothetical overlapping of the two representations. The preference for storing enduring information from a preferred perspective is due to the specific features of the allocentric representation, which maintains enduring object–to–object relations in an orientation dependent manner (Mou et al., 2004). Conversely, the features of the sensorimotor representation determine a preference of reasoning from the physical body position. In situations in which an overlapping of representations occurs, it might be possible that people choose to rely on just one perspective preference, since they are unable to follow both of them. Therefore, it seems that people prefer the sensorimotor framework, reasoning from their changing physical position and learning spatial information from a multitude of different points of view. Then, the learned spatial information might be stored as an allocentric representation, bypassing the constraints of the perspective–dependent representation. Thus, during the hypothetical temporary overlapping of the representations, it is possible that people benefit from both the representational systems simultaneously. In particular, when reasoning about remote described environments it is possible that people acquire spatial information by employing the characteristic features of the sensorimotor representation (i.e., reasoning from their changing physical position) and store it by employing the characteristic features of the allocentric representation (i.e., storing enduring relations).

Furthermore, the hypothetical overlapping of the two representations should affect the relation between the alignment effects, which refer to one of the two representations. According to the assumption that representational systems are somehow related, since they seem to rely on common resources (Sholl, 2001), we might expect an even stronger relation when they are tightly connected by physical movements. Thus, the enconding and sensorimotor alignment effects might not be totally independent. Indeed, as a consequence of the multisensory pattern of information gained by walking, it appears that the decrease of the encoding effect corresponds to the increase of the sensorimotor effect, suggesting that the two alignment effects are not orthogonal (Experiment 3). It is noteworthy that such a relation between the alignment effects was not confirmed in the following experiment (Experiment 4). However, the independence of the two alignment effects is still widely debated in spatial cognition literature, since controversial evidence exists for this topic (Kelly et al., 2007; Avraamides & Kelly, 2010).

The topic of the independence of the alignment effects in described environment should be examined by future studies in order to shed light on the relation between the two representational systems, reflected by the relation between the alignment effects. In particular, it would be interesting to investigate how the occurrence of physical movement when reasoning about described environments affects the relation between the alignment effects. At the current state, far too little is known to be clearly inclined to the dependence or independence of the alignment effects in the light of the hypothesis of the overlapping of the two representational systems due to the idiothetic cues gained by physical movements in described environments. Indeed, it is possible that independent alignment effects might coexist even though their representational systems are tightly connected. Future studies should tackle this issue from a theoretical perspective.

## 12.3 Applied perspectives

The need for additional support usually emerges when people deal with unusual or difficult tasks or when they are deprived of their main source of information, namely, sight. Indeed, it is mainly when visual cues are lacking that people rely on alternative sources of information, such as idiothetic or symbolic cues. To emphasize the engagement of these alternative sources of information, we decided in our studies to restrict or eliminate the contribution of visual cues during the experimental sessions, by providing participants only with verbal descriptions or by blindfolding them. Even though our results confirm the effectiveness of these alternative sources of information for temporally “sight–deprived” participants, we do not know whether the same results would emerge by testing participants with visual impairments.

Therefore, future studies should investigate whether spatial descriptions and physical movements positively influence the spatial learning, updating and navigation processes of visually impaired people, similar to what was found for sighted people. Previous studies suggested that people with visual impairments organize spatial information differently from sighted people (Noordzij et al., 2006), partially due to the employment of different spatial learning strategies (e.g., Schmidt et al., 2013). However, in different domains it has been suggested that the experience of physical movement facilitates the acquisition of spatial learning (Thorndyke & Hayes-Roth, 1982), even for visually impaired people (Schmidt et al., 2013). Therefore, we might expect an influence of physical movement on spatial representations in both sighted and visually impaired people, similar to what was found in other domains.

In the case in which the results of such future studies would confirm the positive contribution of spatial descriptions and physical movement on spatial processes of people with visual impairments, interesting suggestions would emerge from an applied perspective. Indeed, those outcomes might find an application in the domain of spatial cognition, in particular in the development of new learning strategies based on physical movements and spatial descriptions. It is licit to expect that further understanding of how visually impaired people elaborate spatial information provided in a verbal description – and consequently how they construct the corresponding mental representation – might contribute to the enhancement of their actual educational system. Therefore, in the light of our findings, future applied studies could lead to the development of innovative spatial learning strategies and navigation systems in room–sized environments for visually impaired people, for example by facilitating the congruency of encoding and testing modalities and by replacing the spatial descriptions with physical movement, when a navigation task is subsequently required.

Another domain in which people have to rely on alternative sources of information (i.e., different from sight) to learn spatial information deals with environments far from people's surroundings. For example, when people have to communicate a route to locations never experienced before, they employ language to provide as much information as possible. It is possible that the structural organization of verbal language at least partially depends on the size of the considered environment. In our experiments we exclusively focused on environments which can be entirely observed as a whole, similar to the definition of the vista environment from Montello (1993).

However, it would be interesting to understand whether spatial descriptions and physical movement maintain their importance in contributing to the construction of spatial representations in larger environments. Indeed, future studies should aim to investigate whether executing physical movements, which mimic the protagonist's motion, positively contribute to spatial learning and updating in larger environments. Moreover, it might be possible that large environments – which cannot be entirely visualized – are more difficult to mentally visualize than room–sized environments, impairing as a consequence the reasoning about the described spatial relations.

The spatial descriptions of large environments seem to be frequently employed in daily life to communicate spatial information about a not directly perceived environment. For example, common GPS navigation devices associate simple verbal information to visual maps in order to communicate spatial routes. By proceeding the research regarding the characteristics of spatial description of distant environments, it is possible to improve the quality of the descriptions through which effective spatial information is provided. Moreover, to improve the validity of their results, future studies should employ ecological situations in which the effects of different characteristics of spatial descriptions on spatial navigation are examined.

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