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ACQUISITION OF SPATIAL KNOWLEDGE DURING NAVIGATION: THE ROLE OF INTERNAL AND EXTERNAL FACTORS

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Introduction

Spatial cognition is the most basic of the cognitive abilities and fundamental for the survival of any organism. In all species the capacity to acquire and to represent spatial information is involved in many crucial activities, such as fleeing from predators, finding food, or finding the way home. The processes involved in constructing spatial representations of space have been studied intensively since the concept of "cognitive maps", introduced by Tolman (Tolman, 1948) in the first half of the 20th century.

To effectively construct a spatial representation, humans (and other animals) must to be able to learn, remember, and utilize information about the spatial layout of their environments. Such information can be learned from many different sources. In particular, humans have the capacity to construct abstract spatial representations through the use of symbolic supports such as language and maps.

Finding the way round a large-scale environment, one of the multiple ways of learning and using information about space, indicated in literature with the term "*wayfinding*", has received considerable attention in the research over the past 50 years (for review Wiener, Buchner, & Holscher, 2011). The term "wayfinding" has originally been introduced by Kevin Linch (in "The image of the city", Linch, 1960) and then used by Golledge (1999, p. 6) indicating "the process of determining and following a path or route between an origin and destination". Montello (2001) defines wayfinding, the cognitive component of navigation that require decision making and/or planning processes and involve some representation of the environment, distinguishing it by locomotion, the movement of one's body around the environment.

This dissertation focused on the acquisition of spatial knowledge during navigation analyzing the role of cognitive processes and individual and external factors on construction of a spatial representation. About cognitive factors, as first suggested by Lindberg and Garling (1981), working memory is a prime candidate for the set of cognitive systems that might provide such limited capacity support in navigation tasks. Previous studies showed that individual differences, such as gender (Lawton, 1994), cognitive styles in spatial representation (Pazzaglia & De Beni, 2001; Nori & Giusberti, 2003), sense of direction in navigation (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002; Kozlowski & Bryant, 1977), the ability to encode and maintain in memory information provided in the environment over time (Hegarty, Montello, Richardson, Ishikawa, &, Lovelace, 2006), influence the construction of a cognitive map.

In addition to internal factors, some characteristics of the source learning, such as a virtual or real environment (Richardson, Montello, & Hegarty, 1999), or the presence or less of landmarks in the environment (Wan, Wang, & Crowell, 2012), might influence the construction of a mental representation and the question then arises of what specific effects these variables have on the characteristics of the spatial representations generated.

Chapter 1.

Theoretical frameworks: the factors that might influence the construction of a mental representation

1.1. Theoretical frameworks of spatial mental representation: landmark -route -survey

Trowbridge's (1913) early paper aside, many researchers would date the modern period of cognitive studies of acquiring spatial knowledge to the work of Tolman (1948). His classic 1948 paper *`Cognitive maps in rats and men'* introduced the term *`cognitive map'* explaining the ability of rats to make fewer errors and find shortest routes reaching the food box as the construction of a spatial representation, "a field map of the environment" (Tolman, 1948).

The process of construction of a spatial representation (or cognitive map), called cognitive mapping (Downs & Stea, 1973), implies the acquisition of knowledge about the identities and places of landmarks, the path connections between places, distances, and directions between places.

Klatzky, Loomis, Beall, Chance and Golledge (1998) identified the use of an egocentric or allocentric reference frame as ''a means of representing the locations of entities in space,'' leading to distinct spatial representations conveying different types of information. Research focused on the characteristics of distinct spatial representations and the process implied in the acquisition of spatial knowledge in new environments.

Siegel and White (1975) proposed a theoretical framework for describing and explaining the process of knowledge development over time in new environments *(called spatial cognitive microgenesis)*. Many their ideas come from Piaget's spatial ontogeny, including the idea about the progression from topological to metric knowledge (Piaget & Inhelder, 1967; see also the book *L'Espace Chez L 'Enfant* (translated as *The Child's Conception of Space*; Piaget and Inhelder 1956). In their framework, internal representations of spatial knowledge of a new place progress over time from an initial stage of landmark knowledge to a stage of route knowledge to an ultimate stage of survey knowledge. Landmark knowledge is based on discrete objects, that serve important role in the organization of spatial knowledge. Route knowledge consists of information about the order of landmarks and associated decision (e.g. turn right and go straight). In according to Siegel and White's model (1975, see figure 1.1) such knowledge does not contain information about metric distance and direction. The final stage of their framework is survey knowledge that develops when knowledge about separate route are integrate in a complex network. Survey knowledge represents distance and directional relationships among landmarks, including those between which direct travel has never occurred.

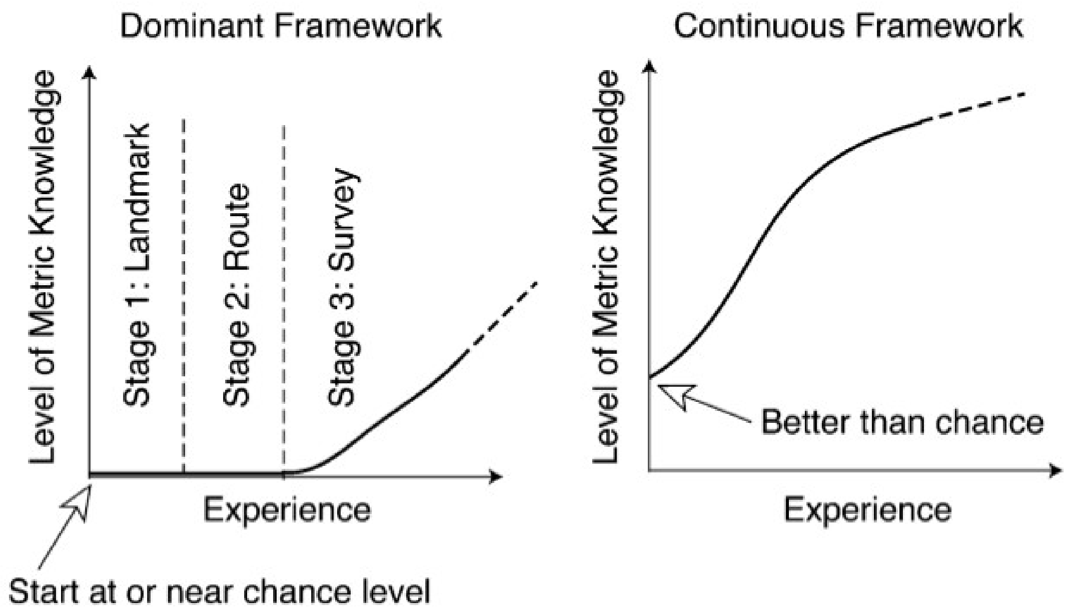
Although their framework has not received many empirical support (see Cohen & Schuepfer, 1989, for developmental processes; and Evans, 1980), their model was influential and became the "*dominant framework*" (see figure 1.1), as called by Montello (1998), for about 20 years. For example, Golledge (1999) distinguished between *declarative knowledge,* about of landmark and route and *procedural* knowledge including the rules for linking landmarks and routes. He supposed that only after the acquisition of declarative and procedural knowledge is possible to infer a configurational representation, emphasizing the sequential nature of spatial knowledge suggested by Siegel and White.

However several researchers have criticized the strict Piaget type developmental theory of spatial knowledge acquisition as interpreted by Siegel and White (e.g. Liben, 1981). Allen (1988) confirmed accurate route-learning without available landmarks for adults. Garling, Book and Ergezen (1982) found that subjects remembered locations of landmarks in an unfamiliar part of a Swedish town before they learned the system of paths accurately and these results corresponded with the findings from Evans, Marrero and Butler (1981). Even survey knowledge can be acquired during the initial period of an environmental learning task (Holding & Holding, 1989) or after brief experience (Montello & Pick, 1993). In a review Blades (1991) has pointed out that even young children are already able to walk routes previously learned after minimal experience and that landmark information is not always necessary for successful wayfinding. The author supports the idea that the ability to use landmarks and routes to structure the environment is probably acquired simultaneously at an early stage of development rather than in successive processes and that landmark and route knowledge then develop conjointly to a progressively global (survey-like) environmental knowledge.

Particularly troubling, as pointed out by Montello (1998), are the idea that there is a qualitative transition sequence between three distinct types of spatial knowledge: landmark, route and survey. People can acquire survey knowledge only after landmark and route knowledge. Montello proposed an alternative framework, "*continuous framework*", positing a continuous (or quantitative) development of metric knowledge. In Montello's framework "there is no stage at which only pure landmark or route knowledge exists". People with minimal exposure to a new environment (on the order of seconds or minutes), can perform tasks that require some metric configurational knowledge—such as taking shortcuts, returning directly back to starting locations, and estimating distances and directions directly between places (e.g., Klatzky et al., 1998; Landau, Spelke, & Gleitman, 1984; Loomis, Klatzky, Golledge, Cicinelli, Pellegrino, & Fry, 1993). "As familiarity and exposure to place increase, there is a relativity continuous increase in the quantity, accuracy and completeness of spatial knowledge (quantitative rather than qualitative shift)" (Montello, 1998) (see both models in figure 1.1).

To investigate whether the acquisition of spatial knowledge is sequential or continuous, Ishikawa and Montello (2006) conducted a longitudinal experiment assessing spatial knowledge of participants for ten consecutive weeks. Participants travelled through the same route once a week and then after each exposition of the environment performed experimental tasks, such as named the landmarks in order of appearance, estimated directions, route distances, and straight-line distances between landmarks and sketched map. In addition they examined the role of individual differences in sense of direction asking participants to fill in a self- report, the Santa Barbara Sense of Direction Scale (Hegarty et al., 2002). They found that participants were able quickly to acquire some metric knowledge of environmental layout, as evidenced by their accurate performance on directions and distances judgments and by the ability to sketch maps after first exposure. However, this occurred only for individuals with good sense of direction while others, with low sense of direction, did not construct a configurational representation nor after ten exposures to the environment, emphasizing the role of individual differences in the construction of survey representation.

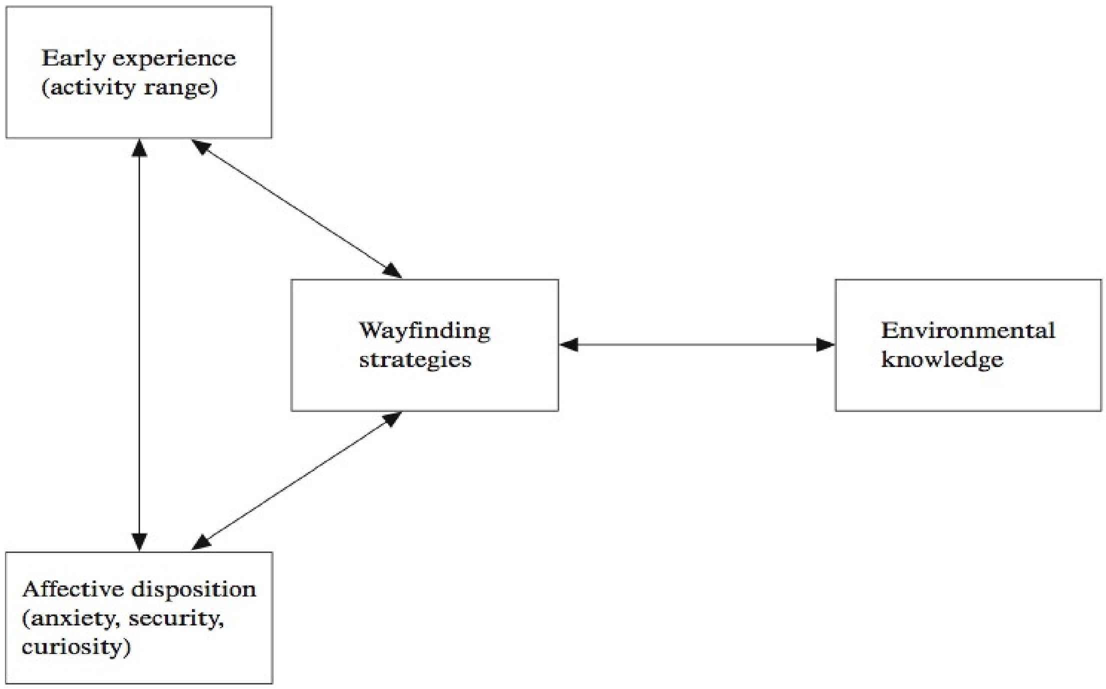
Figure 1.1 Acquisition of spatial knowledge: Siegel & White's model (1975) vs Montello's model (1998)



Kitchin (1996*b*), in his theoretical framework (see figure 1.2), emphasized the subject's *interactive* behavior within the real world, involving environmental and social interaction, and his or her active role in the choice of a particular environmental strategy. Within his conceptual schema, environmental learning and the acquisition of environmental knowledge are discussed with respect to a dynamic memory system that enables the individual to discriminate, learn and store new knowledge guided by previous information that is stored in long-term memory. In other words, the attention of subjects on particular spatial properties (e.g. directions) instead of other cues (e.g. landmarks) in wayfinding is influenced by his or her prior experience and its emotional context.

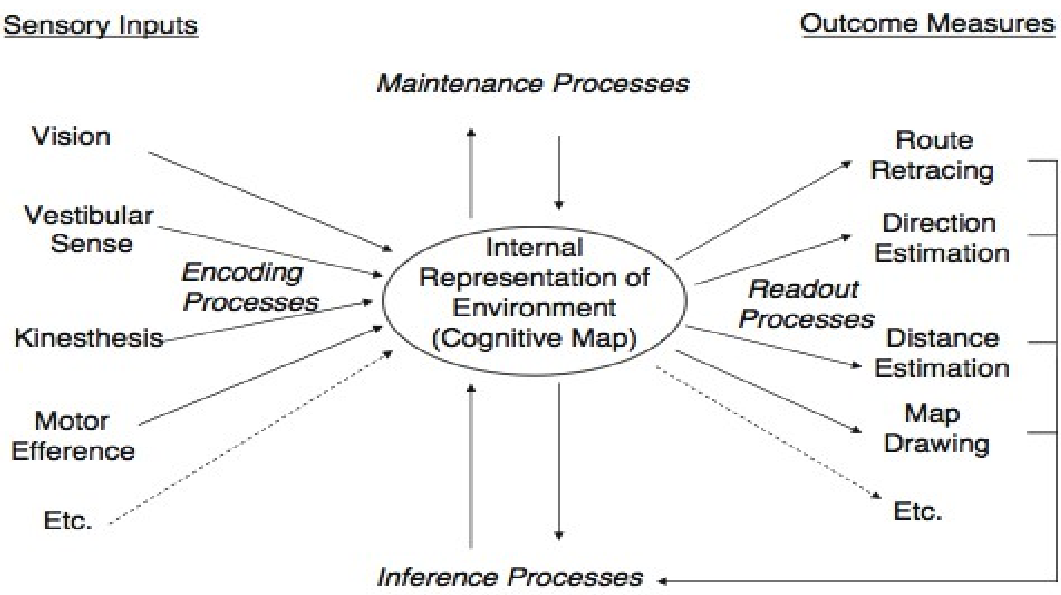
This interactive approach enables research not only to analyze individual differences in environmental learning and development but also to examine the effects of external and internal mediators on these processes.

Figure 1.2 Interactive model of environmental learning (Kitchin, 1996b)



More recently Hegarty et al., (2006) proposed a model of spatial knowledge that emphasizes how different outcome measures of learning can be used to test different spatial representations. In fact the layout of the environment must be, first, encoded from the various sensory inputs available, leading to an internal representation of the environment, which might be a route or a survey representation. Several outcomes can be used to assess constructed spatial representations. However some outcomes are measures of route representation and others of survey representation. More specifically, outcomes, such as retracing route, involve a route representation, while map drawing or estimation of direction involve a survey representation. They hypothesized that the type of spatial representation can be influenced by individual differences in large-scale spatial cognition. More specifically they indicated three main sources of individual differences in large-scale spatial cognition: ability to encode spatial information from sensory experience, ability to maintain a high-quality internal representation of that information in memory, and ability to integrate all information and construct a successful representation. In their model the process of maintaining and integrating all information in a spatial representation has a central role (see figure 1.3).

Figure 1.3. Schematic depiction of perceptual and cognitive processes involved in the acquisition spatial knowledge (Hegarty et al., 2006).



1.2 Role of individual differences in the acquisition of spatial knowledge

The construction of a spatial representation subsumes several factors, including amount of available knowledge, the ability to form spatial representations and available processes for acquiring and using environmental knowledge. Given the complexity of the construction of a spatial representation, it is difficult to predict a person's skill in navigating successfully because many factors are involved in this skill (Prestopnik & Roskos-Ewoldsen, 2000). Garling, Book, and

Lindeberg (1984) and Kitchin (1994) found that both external (i.e., environmental) and internal (i.e., personal attributes) factors are involved in predicting wayfinding. About internal factors, several studies showed that environmental ability is predicted by self-reported sense of direction (SOD). Such a measure was first introduced by Kozlowski and Bryant (1977). These authors simply asked people to rate on a seven- or nine-point scale "How good is your sense of direction (SOD)?" In two experiments, they asked participants to point to campus landmarks imaging to stay at a specific location on their campus. The correlations between the pointing error and the self-report item were .49 and .51 for the two experiments, respectively. In a third experiment, participants were led through an underground tunnel system and their task was to point back to the entrance of the tunnel from the end of the route. Participants, classified as good or poor in SOD on the basis of the self-report question, showed a difference in pointing error of 30°, in favor of the good SOD participants. Hegarty et al. (2002) developed a standardized self-report scale of environmental spatial skills, Santa Barbara Sense of Direction Scale (SBSOD) suggesting that the correlation of self-report SOD with environmental spatial cognition, is more highly with measure of survey knowledge, such as pointing task and when spatial knowledge is acquired by direct navigation (Kozlowski & Bryant, 1977; Montello & Pick, 1993; Sholl, 1988; Sholl, Acacio, Makar & Leon, 2000)

Sense of direction is related, as reported by Prestopnik and Roskos-Ewoldson (2000), to survey strategy in navigation task. Survey or *orientation strategy,* as called by Lawton (1994), is based on reference to global reference points, such as compass directions in outdoor environments, or the general building configuration in indoor environments, while r*oute strategy is* based on information about a route to be followed, such as when and where to turn.

Pazzaglia, Cornoldi, and De Beni (2000) described, also, landmark strategy, focused in particular on the visual features of landmarks, such as their shape, color, and verbal labeling. They proposed the Questionnaire on Spatial Representation (QOS) distinguishing among landmark, route and survey representations and the respective strategies.

Survey, route and landmark strategies were often equally efficient in wayfinding tasks; some studies suggested that in indoor (Holscher, Vrachliotis, Brosamle, & Knauff, M., 2006) as in outdoor (Denis, Pazzaglia, Cornoldi, & Berto, 1999) complex environment, survey strategy did not guarantee the better way finding performance. Denis et al., (1999) showed that landmark-centered individuals performed a wayfinding task in the city of Venice better than the high- survey ones (Denis et al, 1999). In a complex multi- level building, Holscher et al., (2006) supported that the use of survey strategy is accompanied with getting lost. This confirms Passini's (1984) study, which demonstrated that some individuals with poor configurational understanding of an environment can successfully move inside it, even if route strategy is more frequently associated to a high level of spatial anxiety (Lawton, 1994).

The use of specific strategy are often gender related. Women typically report navigating on the basis of local landmarks and familiar routes, whereas men report using cardinal directions, environmental geometry and metric distances (Chai & Jacobs, 2009; Lawton, 1994). Gender differences occur from the age of 8 onwards. In the studies of Matthews (1986, 1987*a*) boys' maps of their home area were more detailed (number of elements), more accurate (positioning), more extended in dimension, and involved a higher degree of complexity than that of girls of a similar age.

Several theories were proposed about gender differences. In terms of causal factors, there is increasing evidence for the influence of sex hormones on navigational performance (Bell & Saucier, 2004; Driscoll, Hamilton, Yeo, Brooks, Sutherland, 2005), in terms of evolutionary theories (Jones, Braithwaite, & Healy, 2003), gender differences in the use of environmental strategies perhaps result from a different range of spatial experience for boys and girls (more limited for girls). However, superior performance by males is not found in all tasks at the environmental scale. It is typical when people learn spatial layout from map (Coluccia, Iosue & Brandimonte, 2007) or virtual environment (Ross, Skelton, & Mueller, 2006), but from real environment the differences between genders are less consistent (see Coluccia & Louse, 2004 for a review; Holscher et al., 2006).

1.3 Role of working memory in the acquisition of spatial knowledge

The quality of internal representation could be influence by aspects of memory. In fact in environmental learning that involves the ability to encode, maintain and integrate information in internal representation, a key factor is working memory.

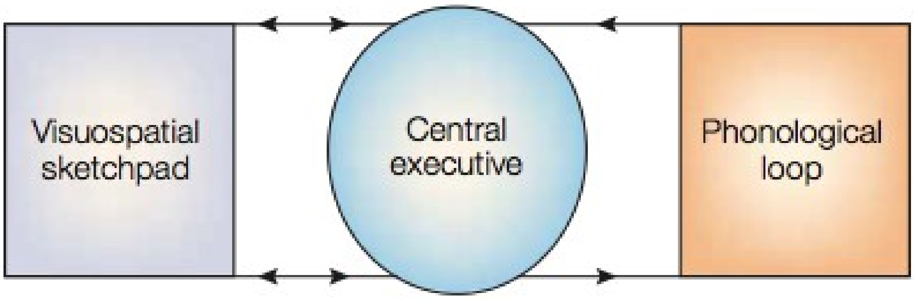
The term 'working memory' (WM) seems to have been invented by Miller, Galanter and Pribram (1960), and was adopted by Baddeley and Hitch (1974) to emphasize the differences between their three-component model and earlier unitary models of short-term memory (STM). More specifically they proposed a three - component model of working memory in place of the unitary system. It comprises a control system, the central executive, and two storage systems, the visuospatial sketchpad (visuo-spatial working memory, VSWM) and the phonological loop (verbal working memory (VWM) (see figure 3).

Baddeley and Hitch (1974), using secondary tasks to deplete the availability of STM in subjects performing tasks, such as learning a route, assumed the involvement of working memory.

Dual task paradigm is an approach to studying the contributions of the two working-memory slave systems to navigation task. It can distinguish which aspect of working memory is being utilized during performance of different tasks. For instance, articulatory interference, which requires participants to repeat some irrelevant verbal material (e.g., ba-be-bi-bo-bu) while performing a task, only impairs tasks that utilize the phonological loop; whereas visuo-spatial interference, which requires participants to repeatedly tap a spatial pattern (called "spatial tapping") while performing a task, only impairs tasks that utilize the visuospatial sketchpad. Thus, the performance in navigation tasks should be selectively and negatively impaired by articulatory suppression, if learning a route involves verbal working memory, or by spatial tapping if it involves visuo-spatial working memory (for review Baddeley, 2003).

Lindberg and Garling (1981) conducted one of the first studies on the involvement of working memory in navigation task. They analyzed the possible role of a limited-capacity cognitive system in estimating directions and distances. They asked participants to walk along an unknown path and estimate the direction and distance to the reference points when they stopped. In the concurrent task condition, participants while walking undertook a concurrent task and specifically backward counting. Participants showed increased latency to estimate the location of reference points supporting the idea that the concurrent task impaired navigational performance and generally supported the notion that navigation may require effective use of a limited capacity cognitive system. However, as Garden, Cornoldi, and Logie (2002) pointed out, the work of Lindberg and Garling (1981) gave no indication as to the relative involvement of specific cognitive sub-systems.

Figure 1.4 Baddeley and Hitch' s model of working memory (1974)



Information might be encoded and organized in verbal working memory, as a sequence of route (Allen, Kirasic, Dobson, Long, &, 1996) and provides rigid route representations, often in an egocentric reference frame and based on local landmarks. Otherwise, it might be encoded in spatial working memory as a configuration and develops in observer-independent, survey representations that allow for planning direct paths to unseen goal locations and infer spatial information not directly perceived.

Garden et al. (2002) asked participants to perform a navigation task. They were led by an experimenter around each of two selected routes in the city centre of Padua, and had to remember the route as well as possible because at the end they had to reproduce the learned route (Experiment 2). Experimental groups, had to perform articulatory suppression or spatial tapping dual task during route learning.. The results showed that performing a concurrent task led to a decrease in route-learning performance, confirming previous observations that the reduction on available cognitive resources reduces the efficiency of spatial cognitive activity (Lindberg & Garling, 1981), but, additionally, confirming that both verbal and spatial working memory systems were involved.

Meilinger, Knauff and Bulthoff (2008) investigated the role of verbal, visual, and spatial working memory in learning a route in a virtual environment, with reference to models that distinguish between visual and spatial components of VSWM (e.g. Logie, 1995; McConnell & Quinn, 2000). They used one verbal and two visuo-spatial secondary tasks. One secondary task focused on the visual component, the other one focused on the spatial component of the VSWM. More specifically they used lexical decision task as verbal dual task deciding whether a presented word existed in native language (German). In the visual task, the participants heard times and had to imagine a clock with watch hands. The participants had to indicate whether the watch hands point to the same or to different halves. The participants were explicitly instructed to solve the tasks by imaging the clock. In the spatial task, the participants had to indicate from which direction a sound was coming—either from the left, the right, or the front—by pressing one of three corresponding keys. Results revealed that verbal and spatial dual task interfered more strongly than visual secondary task. The spatial component of WM seemed to be more important than the visual one.

In according with literature, in the acquisition of route knowledge, the information is encoded in both the spatial and verbal subcomponents of working memory (Garden et al., 2002; Meilinger et al., 2008; Wen, Ishikawa, & Sato, 2011, 2013). However researchers have also begun to investigate the relationship between working memory and acquisition of survey knowledge (Coluccia, Bosco, & Brandimonte, 2007; Coluccia, 2008; Wen et al., 2011; 2013).

Coluccia and colleagues (2007) studied the acquisition of survey information from maps. In one experiment (Coluccia, Bosco et al., 2007), participants studied the map of a real place (the Palatino, an archeological site in Rome) while performing either a verbal or spatial secondary task, or with no interference (control group). As a measure of survey knowledge, they recorded the number of landmarks properly placed on a drawn map. Results revealed that the spatial (but not the verbal) secondary task impaired performance, suggesting a selective involvement of VSWM in acquisition of survey knowledge from a map.

Survey knowledge can also be acquired from navigation. However there are individual differences in ability to successfully complete survey tasks after navigation experience alone (without seeing a map). Gender could also be an important factor in the acquisition of spatial knowledge. However while some studies of map learning, (e.g., Coluccia, Iosue et al., 2007), reported that males were more accurate than females, in the acquisition of spatial knowledge from real environment the differences of the gender are less consistent (see Coluccia & Louse, 2004 for a review). In addition, people who report that they have a good sense of direction are better able to complete survey tasks (such as pointing to unseen locations) after navigating in a building than those who report a poor sense of direction (Hegarty et al., 2002; Ishikawa and Montello, 2006). When people are asked about their navigation strategies, those who report constructing survey representations (and not just landmark or route representations) also perform better at survey tasks (Pazzaglia et al., 2000; Pazzaglia & De Beni, 2001).

Recently, a study of learning from navigation (Wen et al., 2011) documented that individual differences in sense of direction interact with subcomponents of working memory in selectively affecting the acquisition of survey knowledge. Wen et al. (2011) asked participants to learn routes from videos while performing verbal, visual, and spatial secondary tasks or with no secondary task (control condition). They showed that participants with a good sense of direction integrated knowledge about landmarks and routes in a survey representations with the support of all three components of working memory reporting worse performance in secondary task conditions. In contrast, participants with a poor sense of direction showed same performance in all conditions failing to construct accurate survey knowledge.

1.4 Role of landmarks in the acquisition of spatial knowledge

External factors include the availability and the degree of landmark differentiation, the degree of visual access to the environment, and the complexity of spatial layout. Weisman (1981) studied the factors that influence wayfinding in buildings and found that plan configuration was most influential, followed by spatial landmarks, spatial differentiation (i.e., physical qualities of the setting, such as color, light, and materials, that made it particular), and finally signage and room numbers. A number of studies have suggested that the complexity of floor plan configuration has the greatest influence on wayfinding (e.g., Haq & Zimring, 2003).

The regularity hypothesis by Thorndyke and Hayes-Roth (1982) assumes that the regularity of an environment has an effect on how rapidly a person is able to learn spatial relationships. If an environment is quite regular, locations may be determined by a coordinated frame of reference (Piaget & Inhelder, 1967) while in an irregular environment, a coordinated frame of reference is difficult to use. However some studies (e.g. Jansen-Osmann, Schmid and Heil, 2007) confirmed *regularity hypothesis* only partly: performance older children and adults was not influenced by environmental structure (irregular vs regular maze) in survey tasks (e.g. direction estimation, map drawing) but only in route task (such as number of turn chosen, distance walked) probably because with increasing age, individuals might be more capable to regularize irregular features, as it was shown in spatial memory research with adults (Tversky, 2000).

Performance in navigation task might depend on the information available to the navigator, and the reliability of available cues. The presence of landmarks in the environment can provide important information to facilitate navigation. Landmarks can help moving animals to estimate distance, recalibrate the path integration system, and reduce path integration errors (Collett & Graham, 2004). Some studies suggested that landmarks are useful to create a route representation and, also, to infer a configurational representation.

Several studies investigated, through the shortcut task, how the presence of landmarks can influence the construction of configural representation in animals. Gallistel (1990) argued that animals demonstrate the possession of a cognitive map through their ability to perform novel shortcuts. In a celebrated example by Gould and Gould (1982), *home triangle paradigm*, bees are first trained to fly consistently and accurately from the hive to two feeding sites. The feeders form two legs of a triangle with the home location at the apex. Changing their home location, animals are able to take a novel shortcut from their displaced location directly to the first feeder, as evidence that they have constructed a mental map of the feeding sites by combining distance and direction information from the learned routes. Some researchers attributed successful shortcut performance to presence of salient landmarks in the environment (e.g. Dyer, Berry, & Richard, 1993).

The utility of landmarks to perform novel shortcut is confirmed in humans also. Some studies showed that in the absence of visual landmarks, humans can learn two legs of a triangle with some accuracy, but performance on novel shortcuts is inaccurate and highly variable reporting angular deviations on the order of 30° respect to correct position. Shortcuts are much more accurate and precise only when stable landmarks are present (Foo, Duchon, Warren & Tarr, 2007; Foo, Warren, Duchon, & Tarr, 2005; Riecke, van Veen & Bulthoff, 2002).

Some studies added that not all landmarks along the route are equally relevant. In fact studies have reported that object placed at an intersection (a decision point), are more likely to be remembered than object placed at not decision point (Blades & Medlicott, 1992). However there are situation in which objects at decision point are not helpful, such as the same landmark placed at different decision points. In fact as shown in Janzen's fMRI study (Janzen & Jansen, 2010), same object presented twice at different decision points evoked more errors than objects presented twice at a non-decision point and even more than objects presented at a non-decision point and a decision point. They showed, also, that specific neural mechanism exist to distinguish between helpful and not helpful information. They found that the activity in the parahippocampal gyrus increased for objects placed at a decision point only once as compared to objects placed at non-decision points. When same objects appeared at different decision point increased the activity in areas involved in higher cognitive functions, i.e. the frontal lobe for compared to objects that appear at different non-decision points.

In addition the advantage of the presence of landmarks was not confirmed by all studies in literature. Jansen- Osmann & Fuchs (2006) showed that the presence of landmarks had no benefit on spatial survey knowledge. The advantage of the landmarks might depend on some internal factors, such as the type of strategy typically used to navigate through an environment (Wan et al., 2012). In fact in Wan's study (2012), participants were asked to travel along pathway (with or without landmarks) and when they arrived at the end of the pathway, they were asked to return to either the origin or one of the landmark locations. They found no differences in learning condition with or without landmarks explaining that lack of landmark advantage might mean that participants did not use strategy based on landmarks.

1.5 Role of instructions in the acquisition of spatial knowledge

Another potential external factor that could influence the acquisition of spatial knowledge is the intention of learner in the acquisition of spatial knowledge.

Early work (Hasher & Zacks, 1979) suggested that the acquisition of spatial information is not affected by intention of learner. In according with the theory of Hasher and Zacks (1979), the acquisition of spatial knowledge is not effortful but is acquired automatically and are not affected by learner state or environmental characteristics. They proposed a number of criteria to determine the automaticity of process. One of criteria, that they propose to distinguish automatic from effortful process was the influence of intention of learner. Effortful process, in contrast to automatic, would be affect by this variable.

Recent studies showed through various methods the influence of intention on the acquisition of spatial knowledge. The intentions guide the attention during learning, serving as anchors for selecting relevant stimuli (Britton, Meyer, Simpson, Holdredge, & Curry, 1979; LaBerge, 1995). In developmental psychology, it was shown that providing a goal-based activity can modulate spatial learning. Children specifically instructed to acquire the overall configuration of a funhouse, explored the environment in different manner than children instructed to learn a route. Different instructions led different types of spatial representation. Indeed children with layout goal had better configural knowledge than children with a route goal (Gauvian & Rogoff, 1986). These results were a demonstration that the acquisition of spatial knowledge not necessary proceeds step by step, as suggested by Siegel & White, but a survey intention can led immediately at the construction of survey representation of the environment even after the first exposition with it.

Magliano, Cohen, Allen, and Rodrigue (1995) investigated the impact of intention on adults suggesting a compromise between Siegel and White's model (1975) and studies that proposed a superiority of the intention in the acquisition spatial knowledge. Specifically they showed that participants with route instruction performed better in task involving both route and survey representation compare to landmark ones, participants with configurational instruction had superior performance only in survey task. These results supported the idea the instruction facilitate the acquisition of the type spatial knowledge that they suggested and also of knowledge of next spatial steps: participant with landmark instruction emphasized not only landmark knowledge but even route and survey that require it; participants with route instruction performed better in task involving both route and survey representation compare to landmark ones, participants with configurational instruction had superior performance only in survey task.

Taylor, Naylor and Chechile (1999) extended this results by showing that intentions influenced the construction of spatial representation in map learning also. Participants having a survey goal during map study increased performance on allocentric (bird's-eye perspective) tasks such as Euclidian distance estimation, whereas the route goal increased egocentric (first-person perspective) task performance such as route distance estimation.

Brunye & Taylor (2009) confirmed previous results through ocular movements measure. They showed that for a survey goal eye movements are focused towards elements critical to gathering information about the overall layout of the environment: buildings, and compass coordinates. The route goal, in contrast, biases attention towards the streets and street names that will comprise all routes through the environment.

It is evident that such contextual factors can lead to large differences in the complex process of the acquisition of spatial knowledge.

1.6 Acquiring spatial knowledge in virtual and real environment

Between external factors, not of minor relevance, is the source of acquiring spatial knowledge. People acquire spatial knowledge via several different sources (Montello, Waller, Hegarty, & Richardson, 2004). One may first distinguish direct from indirect sources. Direct sources involve the acquisition of spatial knowledge directly from the environment via sensori-motor experience in that environment. All other sources may be termed indirect or symbolic. They are symbolic because they transmit spatial information by exposing people to simulations of the environments to which they refer. Indirect sources include static pictorial representations, such as maps, and dynamic pictorial representations, such as movies and animations, commonly called “virtual environments”. Different VEs include desktop displays, projected displays, caves, augmented realities, and fully immersive systems.

Different sources involve different involvement of body movement. Previous studies suggested that sources that depend on whole-body locomotion provide proprioceptive information allowing to integrate movement information so as to maintain orientation.

Major question is about how different sources can affect memory structures and processes involved in spatial learning. More specifically first issue concerns *orientation specificity or learning perspective:* spatial memory representations are stored usually in the same perspective from which a spatial layout was viewed during learning. This assumption, as shown, to be valid for spatial representation derived from VEs, or direct experience, and maps also. People use the same schema of reference adopted in learning spatial knowledge *(viewpoint-dependent)*. Acquiring spatial knowledge by map leads to an allocentric representation based on allocentric schema of reference;

acquiring spatial knowledge by navigating leads to an egocentric representation based on egocentric schema of reference.

A second issue central to the question of whether memory structures and processes vary with spatial knowledge sources concerns the distinction between *route* and *survey* knowledge.

Several studies support the idea that the acquisition of route knowledge is facilitated by direct travel. Survey knowledge appear less precise when acquired from direct and virtual experiences compared to learning map.

However there are some studies suggested that the accuracy of spatial representation is same when spatial knowledge is acquired both by direct experience in real and virtual environment.

For example, Ruddle, Payne, & Jones (1997) examined people's spatial representations formed from desktop VEs by replicating Thorndyke and Hayes-Roth's (1982) classic study. Participants learned the layout of the same floor. After nine daily learning trials, participants showed similar levels of distance estimation, pointing, and navigation ability as did participants who navigated the real-world building in Thorndyke and Hayes-Roth's original study. Ruddle et al. (1997) concluded that, given sufficient experience, people are able to learn the spatial knowledge of a VE in the same way that they learn from the real world. Other researchers has reached the same conclusions, especially with respect to the use of VEs to acquire route knowledge (e.g. Waller, Knapp, & Hunt, 2001).

The construction of survey representation by navigating in a virtual environment appear to be more difficult. A possible reason could be that acquiring survey knowledge require more cognitive resource than route knowledge and VEs demand fewer conscious cognitive resources.

Despite the potential difficulties that VEs may have in enabling the acquisition of survey knowledge, some studies have suggested that it is possible. For example, the study by Richardson et al. (1999), included a third group of participants who learned the two-storied building from a desktop VE, in addition to the map and walk groups. Participants of three groups performed in at same level distance- or pointing-estimation within the same floor, suggesting that similar types of spatial knowledge had been acquired among the groups. However, VE learners performed worse in direction and distance estimates between the two floors. Sketch maps by these participants, also, stressed the difficulty to understand the relative vertical orientations of the two floors underlying the less accuracy to integrate the two floors in a global configuration.

INTRODUCTION OF THE EXPERIMENTS

The main question of this dissertation is: do we need the same type of memory for retracing route and finding a shortcut? In other words: which type of memory is involved in the construction of route and survey representation?

To successfully retrace a route it is necessary to acquire route knowledge during navigation focusing on the landmarks available in the environment and encoding the routes and turns along the path on the egocentric scheme of reference. To efficiently find a shortcut it is necessary to construct a survey representation in which all elements are interrelated with each other in a global configuration.

In research the main question concerns the role of working memory (WM) in the construction of a spatial representation during navigation. According to Baddeley's model (1986), working memory is not a unitary system, but it is possible to distinguish an attentional control system—the central executive—and at least two subsystems—the phonological loop and the visuospatial sketchpad, which encodes and maintains verbal information and visuospatial information, respectively (Baddeley & Hitch, 1974). Environmental information is probably encoded in visuospatial working memory (VSWM), but it might be encoded in verbal working memory (VWM), as a sequence of route directions (such as "at the bar turn left, then right, then go ahead") (Allen et al., 1996).

Some researches investigated the role of working memory in the construction of route representation showing the involvement of both subcomponents of working memory (Garden et al., 2002; Meilinguer et al., 2008). However it remains unclear the involvement of working memory in the construction of survey knowledge.

A series of four experiments was carried out. In all experiments we investigated the role of both subcomponents of working memory by classic paradigm of dual task. Participants learned a route in combination with verbal (articulatory suppression) or spatial (spatial tapping) secondary task, which involves verbal and visuo-spatial WM respectively.

Impaired performance in a dual task condition, relative to the control condition, supports the notion that the same subcomponent of working memory is involved in the primary and secondary tasks (Lindberg & Garling, 1981).

The project of research opens with Experiment 1 aimed to investigate how verbal and spatial working memory are involved in the acquisition of route and survey knowledge during navigation in a virtual environment.

In Experiments 2 and 3 we restricted the focus on the acquisition of survey knowledge analyzing the role of internal and external factors. Recently some frameworks, about the process of acquisition of spatial knowledge, suggested that the construction of survey knowledge is not a final step of a progressive spatial process, but it depends on several factors such as individual differences in sense of direction (Montello's framework, 1999), the way to interact with the environment (e.g. sense of anxiety) (Kitchin's model, 1996) and the ability to maintain spatial information in working memory in a configural representation (Hegarty et al., 2006).

In Experiment 2 we analyzed the role of WM and individual differences in the acquisition of survey knowledge during navigation in a real environment. In Experiment 3 we extended the analysis on external factors: finding shortcuts could be influenced not only by individual differences but even by external factors, such as the presence of landmarks. Some researches, in fact, proposed that landmarks can be helpful to find the shortest route to reach the goal (Foo et al., 2005). However it remains to be investigated whether and how external (presence/absence of landmarks) and internal (individual differences in sense of direction) factors interact. In Experiment 3 we analyzed whether the presence of landmarks is more helpful for people with low sense of direction in finding shortcuts.

The final question, considered in Experiment 4, is whether the construction of spatial representation can be modulated by instructions received before navigation and how they influence the involvement of WM. The few studies that analyzed the influence of the instruction (Magliano et al., 1995, Taylor et al., 1999; Brunye et al., 2009; studies with children: Gauvain & Rogoff, 1986) suggested that the instructions guide navigation behaviour leading to different spatial representations, but the processes involved need to be approached widely. In this last experiment we investigated whether different instructions modulate the involvement of WM.

All experiments followed the same general procedure: all participants while navigating in a route in virtual (Experiment 1, 3 and 4) and real (Experiment 2) environment performed a secondary task. After the navigation, participants performed the reproduction of the route, pointing task, shortcut task and drawing map.

A synthesis of the specific goals and structure of the experiments is presented in table 1.1.

Table 1.1. Synthesis of the contents: goals and measures used in the experiments.

Goal	Experiment	Measure	Paradigm
Analysis of the involvement of VWM and VSWM and individual differences in the construction of route and survey spatial representation during navigation in a virtual environment	Experiment 1	Reproduction – shortcut and pointing tasks	Dual task & Individual Differences
Focus on the acquisition of survey knowledge during navigation:			Dual task & individual differences
- Role of VWM and VSWM and individual differences in the construction of survey representation during navigation in a real environment	Experiment 2	Shortcut and drawing map	
- Role of VWM and VSWM, individual differences and landmarks in the construction of survey representation during navigation in a virtual environment	Experiment 3	Shortcut and pointing task	
Effect of the instruction and WM on the construction of route and survey spatial representation during navigation in a virtual environment	Experiment 4	Reproduction – shortcut and drawing map	Dual task & Individual Differences

Chapter 2

The involvement of spatial and verbal working memory in the acquisition of route and survey knowledge during navigation in a virtual environment

EXPERIMENT 1

Introduction

Previous studies showed clearly that during navigation in real (Garden et al., 2002) and virtual environment (Meilinger et al., 2008), encoding and organizing the information in a route representation involves verbal and spatial working memory. They revealed, through dual task paradigm, that the ability to reproduce a route needed verbal and spatial working memory, while visual working memory played a minor role (Meilinger et al., 2008). Overloading verbal and spatial working memory during navigation did not follow to encode information necessary to construct an efficient route representation leading to more errors during retracing of the route.

However, few studies focused on the involvement of working memory in the acquisition of survey knowledge during navigation. Some of them have examined the acquisition of survey knowledge from maps (Coluccia et al., 2007), showing the selective involvement of visuo-spatial working memory. However in the learning map all spatial information is simultaneously visible, there is an allocentric point of view, and the construction of a survey representation merely derives from the map's memorization. In order to build up a survey representation from navigation one has to learn the layout sequentially as one moves through the environment using an egocentric point view, and then integrates all information in a configurational representation.

Moreover in previous research survey knowledge has been measured using performance on map drawing tasks and pointing to unseen landmarks. Both of these tasks can be completed on the basis of survey knowledge (Richardson et al., 1999), although an accurate map can also be completed on the basis of route knowledge (Hegarty et al., 2006). In addition, finding a shortcut is a task used classically to measure whether an animal has constructed a *cognitive map* of the environment (Tolman & Honzik, 1930, pp. 215–232; see also Tolman, 1948; Gallistel, 1990). Indeed, on the contrary to drawing maps, which only needs an external point of view, finding the shortest route to reach a goal, requires the use of both a ego-centered system (to navigate in the environment) and a configurational representation (to individualize the shortest route) (Golledge, 1999).

Given the complexity of the processes involved in the construction of a spatial representation, not surprisingly, humans differ widely in this ability (Blajenkova, Motes & Kozhevnikov, 2005; Hegarty et al., 2006). Potential source of individual difference might be the sense of direction (SOD, Hegarty et al., 2002), the strategy used to encode spatial information about the environment (Pazzaglia et al., 2000) often related to anxiety (Lawton & Kallai, 2002), attitude (Pazzaglia, Poli, & De Beni 2004) and sense of auto-efficacy in navigation tasks.

Literature focused, particularly, on the influence of strategies used in navigation on the construction of a spatial representation. Classically navigators are distinguished in people that make greater use of survey strategy based on a global reference point, such as cardinal direction, Euclidean distance and people that prefer route strategy based on salient landmarks and where to turn at the specific landmarks along the path. Literature revealed that people preferring survey strategy, are also less anxious during navigation (Lawton, 1994, 1996), performing better especially in survey tasks.

Despite the extensive body of literature which has documented the influence of individual differences in the acquisition of spatial knowledge, there has been little research on the extent to how individual differences interact with cognitive processes in the construction of a spatial representation.

To date, studies focused on the relation between sense of direction and working memory in the construction of route representation. Studies in real (Garden et al., 2002) and virtual environments (Baldwin & Reagan, 2009; Wen et al., 2011, 2013), through dual task paradigm, revealed that individuals preferring survey strategy and with high sense of direction, showed worse performance in retracing route when navigated performing spatial dual task, suggesting that they tended to rely more on VSWM than on VWM during navigation. Little is known about the relation between individual differences and working memory in the construction of a survey representation. In Wen' s studies (2011, 2013) participants learnt a route in a virtual environment with verbal, or spatial or visual dual task. They measured the acquired survey knowledge asking participants to draw a map after navigation. Results revealed that participants with high sense of direction performed worse in all dual task conditions, whereas participants with low sense of direction did not show any difference between the conditions. Results suggested that individuals with high sense of direction relied more on VSWM during navigation to encode and integrate the information in a survey representation.

Another big source of individual differences that seems to interact with the involvement of working memory is gender. Men outperform women in learning routes on a map, in a virtual environment, less in a real environment and this difference is also more pronounced in measures of survey knowledge than in measures of route knowledge (see review Coluccia & Louse, 2004).

Given that, the second question of this study is: how does gender interact with working memory in the construction of route and survey representation during navigation?

To sum it up, the aim of this experiment is to explore, through dual task paradigm, the involvement of verbal and spatial working memory in the construction of route and survey representation during navigation in a virtual environment. We investigated, also, how gender difference interact with the involvement of working memory in the acquisition of spatial knowledge during navigation.

We expect to find, based on previous studies, the involvement of verbal and spatial working memory in the acquisition of route knowledge. About survey knowledge, we hypothesized that, if the acquisition of survey knowledge requires people to integrate separate landmarks and routes into a configural spatial representation (Ishikawa & Montello, 2006), VSWM, which is specialized for storing spatial information as a configuration (Hegarty et al., 2006), should play a great role in the construction of a survey representation. In addition, about the influence of gender, whether it is true that males and females differ in tasks involved VSWM, and whether it is true that the construction of survey knowledge involved VSWM, then we expect to find higher gender difference in shortcut task.

Individual differences in spatial anxiety and sense of direction are investigated through the administration of self reports. Participants filled out self-reports and then navigated in a virtual environment in dual task conditions (performing during navigation verbal or spatial dual task) or in control condition (without dual task). After navigation all participants performed retracing route, shortcut and pointing tasks.

Method

Participants

Ninety-two undergraduate students from the University of Padua, participated in the study. They were assigned to one of three groups: 28 (males 14, females 14) performed the learning route with the articulatory suppression task (AS), 34 (males 17, females 17) performed the learning route with the spatial tapping task (ST), and 30 (males 15, females 15) performed the learning route alone, with no dual task, control group (C).

Individual Differences Measure

- Working memory measures

The Corsi Blocks test (adopted from Corsi, 1972). This test consists of a series of nine blocks arranged irregularly on a board. On the experimenter's side of the board, the cubes are numbered to facilitate the administration; the blocks are tapped by the examiner and the participant's task is to reproduce the same sequence of increasing length. Items are presented at a rate of one cube per second.

The Digit Span task (forward and backward versions, adopted by Wechsler, 1974) consists of saying sequences of digits. The sequences vary from 3 to 9 digits in forward version and from 2 to 8 in the backward version. The experimenter orally presents a sequence of digits at the rate of one item per second; subjects have to repeat the digits in the forward and backward orders (according to the proposed version of the test).

- *Self-report questionnaires*
- Spatial Anxiety Scale (SAS, Lawton, 1994)

The scale consists of eight items measuring the level of anxiety that subjects would experience in eight situation presumed to require spatial navigational skills, such as trait a new shortcut without the benefit of a map. Items measure the level of anxiety on a 5 point scale with the two end points labeled *not at all* and *very much*. The eight items were subjected to a principal components analysis (oblimin rotation). All of the items loaded on one factor (alpha coefficient = .80).

- Object-Spatial Imagers Questionnaire (OSIQ, Blajenkova, Kozhevnikov & Motes, 2005)

The OSIQ is a self-report questionnaire designed to assess individual differences in object versus spatial-imagery preferences and abilities. Items are on a 5-point scale with 1 = totally disagree and 5 = totally agree, and ratings “2” through “4” to indicate intermediate degrees of agreement/disagreement. The object and spatial items on the questionnaire are intermixed.

All items were subjected to a principal components analysis (varimax rotation) and the fcators structure was limited of two factors, object (alpha coefficient = .83) and spatial scale (alpha coefficient = .79) (all statistic details in Blajenkova et al., 2005) .

Object and spatial scores were computed by summing the 15 items for each subscale.

- Questionnaire on attitude towards orientation tasks (Pazzaglia, Poli, & De Beni, 2004)

Questionnaire on attitude towards orientation tasks consists of ten items designed to assess the attitude towards orientation tasks. An example of item is “I love to explore different places that do not yet know well to discover new ways and different places”. The attitude was rated on a 4-point scale with 1 = *not at all* and 4 = *very much*. The total score is derived from the summed score of the items (Coefficient α for the scale was .70).

- Auto-efficacy Scale (adapted by Lawton 1994)

The questionnaire consists of same eight item of Spatial Anxiety Scale but changes the question assessing the sense of auto-efficacy in orientation tasks. The sense of auto-efficacy was rated on a 5-point scale, which ranged from *Not at all* efficacy to *Very efficacy* (Coefficient α for the scale was.85).

- Santa Barbara Sense of Direction Scale (SBSOD, Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002)

The Santa Barbara Sense-of-Direction Scale (SBSOD) consists of 15 statements to which participants express their degree of agreement on a 7-point Likert scale. Seven of the questions are stated positively (e.g., “I am very good at giving directions”) and the other eight negatively (e.g., “I very easily get lost in a new city”). All items were scored such that a higher rating indicates a better self-report SOD (i.e., the scoring of positively stated items was reversed). Coefficient α for the scale was .88

- Questionnaire on Spatial Representation (QOS, Pazzaglia, Cornoldi, & De Beni, 2000).

The Questionnaire on Spatial Representation comprises 11 items on spatial abilities: general sense of direction, knowledge and use of cardinal points, outdoor and indoor orienting ability, preference for survey, route, or landmark-centered representations. The total score is derived from the summed score of the items. Questionnaire was tested on a sample of 285 undergraduate students, revealing Coefficient α for all five factors .75.

Virtual environment

We used a virtual urban environment, programmed in Superscape 5.61 software (adapted by Pazzaglia & Taylor, 2007). Information was displayed visually on a computer monitor. The interaction with the environment was controlled with a joystick.

The path was presented in route perspective in which the participants followed, watching the monitor, a specific route. The route, 300 meters long, composed of 12 segments that included 2 roundabouts and 9 turns (4 on the right and 5 on the left). Specifically a segment was defined as the unit of route between two adjacent nodes. The environment contained a 15 landmarks (luna park, bank, parking, etc. you can see all landmarks in Figure 1), distributed as evenly as possible, of which some had label (for example: Scuola Montessori). In the Figure 1 is presented the route in the environment.

Figure 2.1. – Virtual environment -

Secondary Tasks

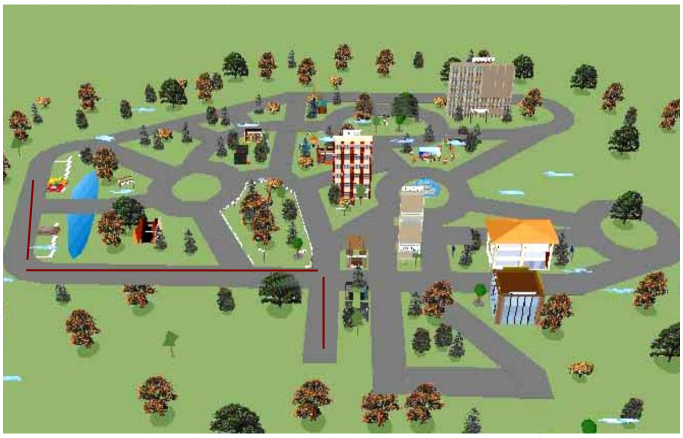
- Spatial Tapping Task (ST). The task consists to tap four cylindrical keys (3 cm height x 3 cm diameter) located near the four corners of a rectangular (30 x 24 cm). An electronic sensor was set up below the board to record the pressure on each key; a display on the left of the board show the number of pressures.

- Articulatory Suppression Task (AS): The task consists to say aloud a sequence of syllables Ba/Be/Bi/Bo/Bu at a rate of one syllable per second. It was recorded using a tape recording the number of syllables in the time available.

Shortcut Task

The task consists to travel in the virtual environment finding the shortest route between start and end-point of the route travelled during the learning session. For moving forward, backward, right, left was necessary to use a joystick. Correct shortcut is depicted in Figure 2.2.

Figure 2.2 - Correct Shortcut of 128 cm measured on the map of the environment.



Pointing Task

Pointing task consists to indicate the direction of the end point respect to starting point. The response was given using a circle (diameter about 4 inches) with a vertical arrow departing from the center and intersecting the circle on the upper part. The arrow designated the imagined facing direction and indicated the start point of the route travelled by avatar. The task consist to draw a second arrow from the center to the boundary, indicating the direction of end point.

Procedure

Participants were tested in single session for about 90 minutes. They were informed to learn an environment path and then their recall was tested using recall task.

Participants, in the first session, filled out the questionnaires in the follow order: Questionnaire on Spatial Representation, Spatial Anxiety Scale, Object-Spatial Imagery Questionnaire, Questionnaire on Attitude towards Orientation task, Auto-efficacy Scale, Santa Barbara Sense of Direction Scale, Corsi Blocks task and Digit Span task.

Then in learning phase were instructed to learn the path observing an avatar moving along the route in a virtual environment. Before starting experimental session participants completed familiarization session in which they move in a sample virtual environment for 5 minutes. Successively participants in learning condition, watched an avatar guide who walked in the virtual environment in route perspective.

Participants were randomly assigned in one of the three dual task condition (ST, AS, C).

Participants in the secondary task conditions first practiced the secondary task alone for 30 seconds and this served as the measure of baseline (single task) performance of the secondary tasks. Participants in the AS condition were instructed to say the syllables ba-be-bi-bo-bu at a rate of one syllable per second. Participants in the ST condition were instructed to tap four keys in a specified pattern on an a board at the rate of one tap per second, without looking at the tapping board.

During learning phase, participants assigned in ST during watching the video illustrating the path they tapped the botton of the board at the end of the route travelled by avatar. Participants assigned in AS during path presentation they repeated the continuously repeated the syllables . In control condition no dual task was performed and participants watched the video of the path.

After learning phase it was followed by testing phase performing in order the retracing route, the shortcut and pointing task. In retracing route was request to retrace learned route in the virtual environment. When participants took wrong direction, they saw on the desktop “wrong direction”.

In shortcut was request to travel in the virtual environment finding the shortest route to reach the end point of the route travelled by avatar. The task finished when they arrived at the end point. Experimenter, watching the registration of the route travelled by participants, traced on a map of the environment the path travelled measuring its length in cm.

Finally they completed the pointing task, where they were told to imagine standing at the starting point of the route and to indicate the position of the end-point drawing an arrow.

Results

Scoring

For retracing route were calculated the number of errors to reach to end-point.

For shortcut it was relieved the length of the route travelled by participant to reach the end-point. We calculated the error of length of the shortcut subtracting the length of shortcut travelled by participants from the length of actual shortcut (128 cm on the map).

For pointing task it was considered the error-pointing between correct position and position that participant pointed.

Measures of Spatial Learning

To examine the effects of the secondary task on spatial learning we conducted a number of analyses of variance (ANOVAs) with type of interference (control, verbal, and spatial) and gender (male, female) as a between subject factors on the following dependent measures: number of errors, absolute pointing error, length of the shortcut.

Retracing route

Analysis of variance (ANOVA) on errors during retracing route showed an effect of type of interference ($F_{(2,90)} = 4.07$; $p = .02$; $\eta^2 p = .09$). Post-hoc comparisons (Least Significant Differences Test, LSD) indicated that both the spatial group ($p = .03$) and the verbal ($p < .001$) group had a significantly higher error than the control group. Results revealed, also, an effect of gender ($F_{(2,90)} = 9.16$, $p < .01$, $\eta^2 p = .10$) with female (M= 3.00; SD = 2.54) reported more errors than males (M =1.52; SD = 2.13) (see table 2.1).

Shortcut Task

The actual length of shortcut (measured in centimeters on the map of the environment) was 128 cm.

Results showed the interaction type of interference X gender ($F_{(2,90)} = 3.45$; $p = .03$; $\eta^2_p = .07$). Post-hoc comparisons (LSD) indicated that in spatial dual task condition females (M = 77.82; SD = 89.39) took significantly longer shortcuts than male (M = 20.53; SD = 30.59) (p = .002). There were no other significant effects (all $p_s > .05$) (see table 2.1).

Error-pointing

Analysis on error-pointing showed an effect of gender ($F_{(2,91)} = 8.42$; $p < .005$; $\eta^2_p = .09$) indicating (Least Significant Differences Test, LSD) that females (M = 63 ; SD = 56.83) performed higher error than males (M = 32; SD = 42.35 (see table 2.1).

Table 2.1. - Measures of spatial learning

Group	Gender	Retracing route (SD)	Error Shortcut 128 cm (SD)	Error-pointing (SD)
Articulatory Suppression	M	2.3 (3.30)	44.21 (33.40)	54.86 (56.40)
	F	3.5 (2.77)	34.71(25.91)	67.86 (58.37)
Spatial Tapping	M	1.18 (1.18)	20.53(30.59)	26.24 (33.80)
	F	3.9 (2.80)	77.82 (89.39)	64.21 (60.96)
Control	M	1.13 (1.36)	31.73 (13.52)	17.37 (26.71)
	F	1.53 (1.06)	40.00 (13.52)	57.27 (53.96)

Individual differences

We examined the role of individual differences in retracing route, shortcut and pointing tasks, correlating the performance with measures of individual differences.

First, we conducted a factor analysis on QOS (Pazzaglia et al., 2000), which revealed the existence of 5 factors that explained 72% of the variance. Factor 1 (Survey Representation) derived from the summed scores of items on general sense of direction and the ability to create survey representation in open and closed environments (items 1, 2, 3c, 4a, 8, 9, 11); Factor 2 (Compass Direction) derived from the use of compass directions in orienting tasks (items 5, 6, 10); Factors 3 (Landmark-centered strategy) and 4 (Route centered strategy) grouped items by preference for a landmark-centered (items 3b, 4c) and route-centered view of spatial representation of space, respectively (3a and 4b). Factor 5 (Visualization strategy) grouped items by preference to make a mental image of the route (7a and – 7b).

Reliability measured by the split-half method (corrected by Spearman-Brown) was .76; distinct Cronbach's alphas were computed separately on the items of the five factors. Alpha values were .85 (7 items), .85 (3 items), .80 (2 items), .68 (2 items) and .66 (2 items), respectively.

Errors in retracing route correlated negatively with Corsi Forward and Backward, indicating that having a poorer spatial working memory span corresponded to poorer performance on retracing learned route (Corsi Forward: $r = -.24$, Corsi Backward: $r = -26$), and Attitude Orientation Scale ($r = -.26$).

Errors in pointing task correlated positively with Object Scale Questionnaire ($r = .26$), showing that less preference for using spatial strategy was associated with a greater error in pointing task. Pointing task, also, correlated with shortcut task, indicating that participants had low performance in pointing task reporting low performance even in shortcut task ($r = .32$).

Discussion

The current study, aimed to investigate which subcomponents of working memory are involved in the acquisition of route and survey knowledge during learning of a route in a virtual environment, through dual task paradigm.

According to literature, we found that both subcomponents of working memory are involved in the acquisition of route knowledge. As a consequence, participants in verbal and spatial dual tasks conditions, performed worse in retracing route compared to control group. Moreover our results suggested that females are less able to construct a spatial representation during navigation in a virtual environment. In fact they performed worse on all spatial task, both route and survey. They reported more errors than males in retracing route and also in pointing task.

The results of performance in shortcut task in which females had lower performance than males only when spatial working memory was overload are interesting. Coluccia and Iosue (2004) proposed that gender differences emerged especially when tasks required a high VSWM load. An interpretation could be that males having high spatial ability and preference for using survey strategy, are not impaired by overloaded of VSWM, whereas egocentric strategies of females are not able to successfully perform tasks in which VSWM is involved.

A minor goal of this study was to investigate how individual differences in WM, spatial anxiety and SOD are involved in navigation tasks. Our results showed a positive correlation between both Corsi forward and backward with retracing route, emphasizing the role of VSWM in the construction of route knowledge during navigation. In addition we added that even the attitude towards navigation task influence the construction of a route representation: a positive attitude towards orientation task leads less errors during retracing of a route.

All together these results confirmed the involvement of both sub-components of working memory in the acquisition of route knowledge (Garden et al, 2002; Meilinguer et al, 2008) and opened new questions about the role of working memory in the construction of survey knowledge. In fact we were surprised to find the involvement of VSWM in the construction of survey representation only in relation to gender differences. An interpretation could be related on the type and characteristics of the environment that we have used. Some studies suggested that the navigation in virtual and real environment involves the same cognitive resource, however the construction of survey representation in virtual environment could be more difficult (Richardson et al., 1999). We have low percentage of participants that individuated the correct shortcut to reach the endpoint of the route. In addition virtual environment was in modality desktop system in which there is not a full immersion, therefore the lack of involvement of the body during navigation might have influenced the performance and the involvement of cognitive resource. In fact the role of proprioceptive and vestibular senses have been shown to contribute to spatial updating (e.g. Klatzky et al., 1998). Moreover the environment was an outdoor space in which there were many landmarks, some visible in many points of environments and therefore probably more helpful in respect to others in finding shortcuts.

We checked these points in Experiment 2 and 3. In Experiment 2 we investigated the role of subcomponents of WM in the construction of survey representation in a real environment and in Experiment 3 we focused on the role of the presence of landmarks during navigation.

Chapter 3

The involvement of spatial and verbal working memory in the acquisition of survey knowledge during navigation in a real environment[1]

EXPERIMENT 2

Introduction

This study focused on the cognitive processes involved in the acquisition of survey knowledge during navigation in a building. Survey knowledge is flexible knowledge of the layout of an environment in which landmarks and routes are encoded and integrated with each other in a global configuration.

As shown in one of the models of learning spatial layout from navigation experience (Hegarty et al., 2006), working memory has a key role in the construction of internal spatial representations. As a person moves through an environment, he or she encodes spatial information sequentially from various sources of sensory information. Working memory is required to maintain this sequentially encoded information, in order to integrate and store it in memory, and to infer new information, such as the global configuration of the environment, which is not viewed directly when moving through an environment (Hegarty et al., 2006).

Recent studies using the dual task paradigm to explore the acquisition of spatial knowledge suggest that, in the case of landmark and route knowledge, the information is encoded in both the spatial and verbal subcomponents of working memory (Garden et al.; Meilinger et al., 2008; Wen et al., 2011; 2013). Researchers have also begun to investigate the

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Experiment 2 is published in Labate, E., Pazzaglia, F., & Hegarty, M. (2014). What working memory subcomponents are needed in the acquisition of survey knowledge? Evidence from direction estimation and shortcut tasks. *Journal of Enviromental Psychology, 37*, 73-79 relationship between working memory and acquisition of survey knowledge (Coluccia, Bosco, et al., 2007; Coluccia, 2008; Wen et al., 2011; 2013).

Coluccia and colleagues studied the acquisition of survey information from maps. In one experiment (Coluccia, Bosco, et al., 2007), participants studied the map of a real place (the Palatino, an archeological site in Rome) while performing either a verbal or spatial secondary task, or with no interference (control group). As a measure of survey knowledge, they recorded the number of landmarks properly placed on a drawn map. Results revealed that the spatial (but not the verbal) secondary task impaired performance, suggesting a selective involvement of VSWM in acquisition of survey knowledge from a map.

Survey knowledge can also be acquired from navigation. However there are individual differences in ability to successfully complete survey tasks after navigation experience alone (without seeing a map). Holscher et al. (2006) investigated wayfinding strategy of familiar and unfamiliar individuals in a multi level building. They showed that to reach a destination in the building, familiar participants with the environment most often chose to walk a well-known route, whereas participants unfamiliar with building chose *central point strategy* sticking as much as possible to well-known parts of the building, even if this requires considerable detours.

Gender could also be an important factor in the acquisition of spatial knowledge. However while some studies of map learning, (e.g., Coluccia, Iosue et al., 2007), reported that males were more accurate than females, in the acquisition of spatial knowledge from real environment the differences of the gender are less consistent (see Coluccia & Louse, 2004 for a review, Holscher et al., 2006). In addition, people who report that they have a good sense of direction are better able to complete survey tasks (such as pointing to unseen locations) after navigating in a building than those who report a poor sense of direction (Hegarty et al., 2002; Ishikawa and Montello, 2006). When people are asked about their navigation strategies, those who report constructing survey representations (and not just landmark or route representations) also perform better at survey tasks (Pazzaglia et al., 2000; Pazzaglia & De Beni, 2001).

Recently, a study of learning from navigation (Wen et al., 2011) documented that individual differences in sense of direction interact with subcomponents of working memory in selectively affecting the acquisition of survey knowledge. Wen et al. (2011) asked participants to learn routes from videos while performing verbal, visual, and spatial secondary tasks or with no secondary task (control condition). They concluded that participants with a good sense of direction integrated knowledge about landmarks and routes to construct survey representations with the support of all three components of working memory. In contrast, participants with a poor sense of direction failed to encode and integrate landmarks spatially to construct accurate survey knowledge.

Questions remain about how different components of working memory are involved in the acquisition of survey knowledge in learning spatial layout in a real environment. Previous studies have examined the acquisition of survey knowledge from maps (Coluccia, Bosco, et al., 2007), from videos (Wen et al., 2011) and from navigation in a virtual environment modality desktop-system. It should be noted that a map is a survey representation in which all spatial information is simultaneously visible, so that constructing a survey representation merely involves memorizing the map. In contrast, in learning from real navigation one learns the layout sequentially as one moves through the environment, one's orientation changes constantly and the amount of spatial information visible at any time is limited (Thorndyke & Hayes-Roth, 1982; Taylor et al., 1999). Learning from a video or from a virtual environment not completely immersive, also involves viewing spatial information sequentially from inside the environment, but it differs from learning from real navigation in that proprioceptive and vestibular information from self-motion are not available. These body-based senses have been shown to contribute to spatial updating (e.g. Klatzky et al., 1998) and previous research has shown a dissociation between ability to learn from a video and from navigation in a real environment (Hegarty et al., 2006).

In this experiment we have used the same dual task paradigm of Experiment 1 to examine the influence of subcomponents of working memory in the construction of a survey representation during navigation by walking in a real environment. In contrast with previous research examining the role of working memory in outdoor navigation in real (Garden et al., 2002) and virtual environment (Meilinger et al., 2008; Wen et al., 2011; 2013), we studied navigation in an indoor environment, which included the added complexity of integrating the locations of landmarks over two floors of the same building (cf. Montello & Pick, 1993; Richardson et al., 1999). To investigate how one acquires survey knowledge, we used classic measures of finding shortcuts, pointing to unseen landmarks, and map completion.

As in previous experiment we hypothesized an involvement of VSWM which is specialized for storing spatial information as a configuration (Hegarty et al., 2006), expecting that should be more difficult for the spatial dual-task group to find shortcuts in the building, to make direction judgments, and to draw an accurate map, compared to the control group. However, it is also possible that spatial knowledge during navigation in real environment might be acquired and maintained through verbal encoding of spatial information, such as sequence of actions, etc. Therefore, both subcomponents of working memory might be involved in the acquisition of spatial knowledge.

A secondary goal of this study was to examine the role of individual differences in sense of direction (Hegarty et al., 2002) and navigation strategy, specifically the strategy used to encode spatial information about the environment (Garden et al., 2002; Pazzaglia et al., 2000; Wen et al., 2011; 2013) through the administration of two self-report questionnaires. According to the literature, people with a preference for using a survey strategy to encode the environment and with a better sense of direction should be more competent in "survey tasks" that require configural understanding of environments (Kozlowski & Bryant, 1977; Montello & Pick, 1993; Sholl, 1988; Sholl et al., 2000, Hegarty et al., 2002¸ Blajenkova et al., 2005).

Method

Participants

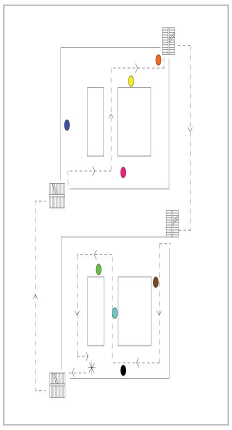
Ninety undergraduate students at the University of California, Santa Barbara, participated in the study. They were assigned to one of three groups: 29 (males 19, females 10) performed the spatial learning task with the articulatory suppression task, 31 (males 20, females 11) performed the learning task with the spatial tapping task, and 30 (males 19, females 10) performed the route task alone, with no dual task.

Materials

Environment

A laboratory building in the Psychology Department on the campus of the University of California, Santa Barbara served as the learning environment [1]. The participants learned a route covering approximately 300ft through the second and third floors. There were eight designated landmarks along the route, four on each floor. Landmarks were chosen for their distinctiveness in the environment (a shower, a sign to a "restricted area", double doors and distinctive chairs were the first four landmark that participants encountered in the third floor; an exit door, pictures on a door, a sign for a "reasoning laboratory" and a mickey mouse toy in a showcase were the other four landmarks in the second floor) . Figure 3.1 shows a map of the building with dots indicating the position of landmarks and arrows indicating the route that participants travelled.

Figure 3.1 Star is the start and the end-point of the route.



Dual Task

- Articulatory Suppression Task (AS): for details see the description in experiment 1.

- Spatial Tapping Task: in this experiment we have used an electronic version of spatial tapping.

The spatial tapping task consists to continuously tap a spatial pattern of five keys on an android keypad at a rate of one tap per second. These included the keys in the four corners and the one in the center of the keypad.

Pointing Task

Pointing task consists to point to unseen landmark in the building. Pointing task responses were recorded by the use of a digital compass.

Map Completion

For the map completion we used an 8.5 × 11 in. blank sheet of paper that showed the perimeters (outer walls) of the two floors and marked the starting point of the route on the second floor and the stairway that they walked (up) at the beginning of the route on both floors.

Self-report Questionnaires

- Santa Barbara Sense-of-Direction Scale (Hegarty et al., 2002)

- Questionnaire on Spatial Representation (Pazzaglia et al., 2000)

It was used an English version of the Questionnaire on Spatial Representation (QOS). For more details about both self reports see the description in experiment 1.

Procedure

Participants were randomly assigned to one of the three experimental conditions. Each subject was tested individually.

Learning Phase

The experimenter led the participants from the starting point on the second floor, upstairs through the third floor and then downstairs through the second floor to the end of the route, which was the same as the starting point (see route in Figure 3.1.). Participants were instructed to follow the experimenter and to pay attention to the landmarks that the experimenter indicated along the route.

Participants in the secondary task conditions first practiced the secondary task alone for 30 seconds and this served as the measure of baseline (single task) performance of the secondary tasks. Participants in the AS condition were instructed to say the syllables ba-be-bi-bo-bu at a rate of one syllable per second. Participants in the ST condition were instructed to tap five keys on an android keypad at the rate of one tap per second, without looking at the tapping board.

After that each participant travelled the route while performing the concurrent task. The number of syllables (in the verbal secondary task) and of taps (in the spatial task) during baseline and navigation were recorded.

When participants arrived at each landmark, they were asked to stop the secondary task, as the experimenter told them the name of the landmark. Then they were asked to name all the landmarks encountered so far in the correct order and were corrected if they omitted a landmark. Then they were instructed to start the concurrent task again before being led to the next landmark.

Pointing Task

At the end of the route, the participants were asked to complete the pointing task. The experimenter again led the participant along the route and at each of the 8 landmarks, instructed him or her to point with a digital compass toward two other landmarks (one in the same floor, one on the other floor) that were not visible from that location, for a total of 16 pointing judgments.

The participants were specifically instructed to ignore whether the landmark was on a different floor and to point in the direction of the landmark as if it was on the same floor. Absolute pointing error was used as a measure of performance.

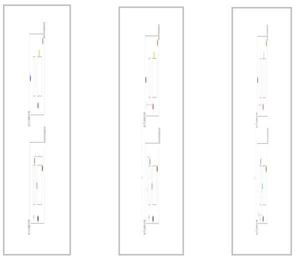
During this phase participants in the dual task conditions continued performing the secondary task while they were walking between landmarks and they were asked to stop the secondary task only for pointing judgments.

Shortcut Task

Three shortcuts were chosen in the building. The end point of the previous shortcut coincided with start point of the next shortcut. Figure 3.2 shows the three shortcuts, in the order they were requested.

For each task, the participants were asked to take a shortcut to the landmark in question. The experimenter followed the participants while they attempted to walk to the landmark by the shortest route, drawing the route that they travelled on a map of the building. The length of the shortcut on the map was measured. Participants were specifically instructed to take the most direct routes without walking quickly.

Figure 3.2 The three correct shortcuts.



Map Completion

Participants were given 5 minutes to complete a map of the building by indicating the positions of all of the landmarks. Sketch maps were scored by counting the number of landmarks in correct positions on the map.

Self-report Questionnaires

In the last phase of the experiment, participants completed the Santa Barbara Sense of Direction Scale (Hegarty et al., 2002) and the Questionnaire on Spatial Representation (Pazzaglia et al., 2000) and reported the strategies that they used for the shortcut and pointing tasks, and their familiarity with the building.

Results

Our analyses were based on data from 89 participants, excluding 1 male participant from the of control group with a high familiarity with the building.

Secondary tasks: Spatial Tapping (ST) and Articulatory Suppression (AS).

To assess performance on the secondary tasks, we calculated the rate of tapping per second (of the ST group) and the rate of syllables per second (of the AS group) in the single task (baseline) and the learning phase. A mixed analysis of variance with one between-subjects factor (secondary task: ST vs. AS) and one within-subject factor (condition interference: single vs. dual-task) was performed on the measures. The results showed a significant effect of the factor interference, ($F_{(1,45)} = 4.28$; $p = .04$; $\eta^2_p = .08$), with higher rates in the dual-task than in the single-task condition, to indicate that navigation affected the performance of the secondary tasks. Neither task, nor interaction interference by task were significant suggesting that the secondary tasks were comparable with regard to their difficulty (see Table 3.1).

Table 3.1 Rate of Tapping/Syllables per second Single and Dual Task Conditions

Group	Single Tasks (SD)	Learning Phase (SD)
Articulatory Suppression	1.13 (.15)	1.17 (.19)
Spatial Tapping	1.11 (.19)	1.21 (.15)

Measures of Spatial Learning

To examine the effects of the secondary task on spatial learning we conducted a number of analyses of covariance (ANCOVAs) with type of interference (control, verbal, and spatial) as a three-level between subject factor, and the following dependent measures: absolute pointing error overall, within and between floors, length of the three shortcuts, and number of landmarks properly placed in the map completion task. Given the importance of gender in spatial tasks, gender was included as a covariate.

Pointing Error

Analysis of covariance (ANCOVA) on absolute pointing error showed an effect of type of interference ($F_{(2,88)} = 3.84$; $p = .02$; $\eta^2 p = .09$). Post-hoc comparisons (Least Significant Differences Test, LSD) indicated that both the spatial group ($p < .001$) and the verbal ($p = .04$) group had a significantly higher absolute error than the control group. Then we assessed separately the error pointing to landmarks within the same floor and between the two floors. Results of pointing error within the same floor showed a main effect of secondary task ($F_{(2,88)} = 4.15$; $p = .01$; $\eta^2 p = .09$), and post-hoc comparisons (LSD) indicated poorer performance in the spatial group than in the control condition ($p < .001$) but no significant difference between the verbal and control groups ($p = .12$). Results of the error pointing to landmarks between the two floors showed, similarly, a main effect of secondary task ($F_{(2,88)} = 3.52$; $p =.03$; $\eta^2 p = .08$), and post hoc comparisons (LSD) indicated a higher mean absolute error of both the spatial group ($p = .01$) and the verbal group compared to the control group ($p = .03$). Table 3.2 shows all means and standard deviations of the three groups in the pointing task. No effect of gender were found on any measures (all $p_s > .05$).

Table 3.2 Absolute error in pointing to landmarks

Group	M Error Pointing (SD)	M Error Pointing Between Floors (SD)	M Error Pointing Within Floors (SD)
Articulatory Suppression	40.83 (20.05)	49.39 (26.94)	32.27 (15.83)
Spatial Tapping	44.34 (20.87)	51.11 (24.84)	37.57 (19.66)
Control	31.21 (10.29)	36.58 (15.74)	25.84 (9.89)
Total	38.92 (18.47)	45.82 (23.58)	32.02 (16.31)

Shortcut Task

For each shortcut task, the measure of performance was calculated as the difference between the actual shortcut and the route taken by each participant (means and standard deviations are shown in Table 3.3). The actual lengths of shortcuts (measured in centimeters on the map of the building) were 9.40, 16.40 and 13.20 respectively for shortcut 1, 2 and 3.

No differences among the three groups were found on Shortcut 1 ($F_{(2,88)} = 1.25$; $p = .29$; $\eta^2_p = .02$) and Shortcut 3 ($F_{(2,88)} = .27$; $p = .75$; $\eta^2_p < .01$). Only in Shortcut 3 we found a main effect of gender ($F_{(1,88)} = 4.10$; $p = .04$; $\eta^2_p = .04$): with males taking a shorter shortcut 3 than females (male M = 6.93, SD = 14.15; female M = 15.14, SD = 23.79).

The analysis of Shortcut 2 showed an effect of the type of interference ($F_{(2,88)} = 3.35$; $p = .03$; $\eta^2_p = .07$). Post-hoc comparisons (LSD) indicated that the spatial group took significantly longer shortcuts than the control group ($p \leq .01$). There was no significant difference between the control and the verbal group ($p = .12$) and no effect of gender was found ($p =.33$).

Table 3.3 Mean performance: difference between the actual shortcut and the route taken by each participant for Shortcuts 1, 2 and 3 (measure: centimeters on the map)

Group	Shortcut 1of 9.40 cm (SD)	Shortcut 2 of 16.40 cm (SD)	Shortcut 3 of 13.20 cm (SD)
Articulatory Suppression	11.58 (17.21)	15.27 (16.39)	11.74 (19.87)
Spatial Tapping	13.45 (26.03)	19.95 (24.79)	9.49 (18.89)
Control	5.69 (12.90)	7.65 (11.04)	8.15 (16.69)

Map Completion

The analysis of the number of landmarks correctly placed in the map was performed on 84 participants. Results showed an effect of the type of interference ($F_{(2,81)} = 4.48$; $p \leq .01$; $\eta^2_p = .10$).

Post-hoc comparisons (LSD) indicated that the verbal ($p \leq .01$) and spatial ($p \leq .01$) groups performed more poorly than the control group, placing more landmarks incorrectly. Table 3.4 shows the means and standard deviations of all groups. No effect of gender was found ($p =.12$).

Table 3.4 Map drawing - Landmarks correctly positioned.

Group	Landmarks correctly positioned (SD)
Articulatory Suppression	5.44 (2.50)
Spatial Tapping	5.58 (2.44)
Control	7.03 (1.50)
Total	6.02 (2.28)

Individual differences

We examined the role of individual differences in performance of the survey tasks, correlating the performance in the Shortcuts, the pointing tasks and the sketch map with the Questionnaire on Spatial Representation (QOS) (Pazzaglia et al., 2000) and the Santa Barbara Sense of Direction questionnaire (SBSOD) (Hegarty et al., 2002). These correlations are given in Table 3.5.

First, we conducted a factor analysis on QOS (Pazzaglia et al., 2000), which revealed the existence of 5 factors that explained 72% of the variance. Factor 1 (Survey Representation) derived from the summed scores of items on general sense of direction and the ability to create survey representation in open and closed environments (items 1, 2, 3c, 4a, 8, 9, 11); Factor 2 (Compass Direction) derived from the use of compass directions in orienting tasks (items 5, 6, 10); Factors 3 (Landmark-centered strategy) and 4 (Route centered strategy) grouped items by preference for a landmark-centered (items 3b, 4c) and route-centered view of spatial representation of space, respectively (3a and 4b). Factor 5 (Visualization strategy) grouped items by preference to make a mental image of the route (7a and – 7b).

Reliability measured by the split-half method (corrected by Spearman-Brown) was .76; distinct Cronbach's alphas were computed separately on the items of the five factors. Alpha values were .85 (7 items), .85 (3 items), .80 (2 items), .68 (2 items) and .66 (2 items), respectively.

Almost all tasks correlated negatively with the Survey Representation factor (Factor 1) of the Questionnaire on Spatial Representation, indicating that having a poorer sense of direction and less ability to create a survey representation corresponded to poorer performance on two shortcuts out of three (shortcut 2 $r = -.32$, shortcut 3: $r = -27$), and greater error in the pointing task, both between floors ($r = -.36$), and within floors ($r = -.29$).

Errors in pointing to landmarks on different floors also correlated negatively with the Compass Direction factor (Factor 2) of the Questionnaire on Spatial Representation ($r = -.22$), showing that a preference for using compass directions was associated with a smaller error in pointing to landmarks on different floors.

The Santa Barbara Sense-of-Direction Scale correlated negatively with shortcut tasks (shortcut 2: $r = -.32$; shortcut 3: $r = -.27$) and with pointing judgments both between ($r = -.37$) floors and within floors ($r = -.27$).

Good performance in the map completion task correlated positively with the Survey Representation factor (Factor 1) of the Questionnaire on Spatial Representation ($r = .40$) and with the Santa Barbara Sense of Direction Scale ($r = .33$) emphasizing the role of sense of direction and the survey strategy in successfully competing these tasks.

We found correlations among the performance of the spatial tasks. The performance in the sketch map correlated negatively with all other tasks indicating that higher number of landmarks collocated correctly in the map corresponded to shorter route in shortcuts task (shortcut 1: r = -.25; shortcut 2: r = -.26; shortcut 3: r = -.40) and to less errors in pointing task both between floors (r = .-51) and within floors (r = - .62).

Finally, we found a positive correlation between the shortcut task and pointing to landmarks on different floors (shortcut 1: r = .30; shortcut 2: r = .23; shortcut 3: r = .39); shorter shortcuts corresponded to smaller errors in pointing between floors, indicating that both tasks were associated with the same ability to create a survey representation of the building.

Table 3.5 Correlation between variables

	1	2	3	4	5	6	7	8	9	10	11
1. Shortcut1											
2. Shortcut2	.18										
3. Shortcut3	.41**	.10									
4. Pointing Between Floors	.30**	.23*	.39**								
5. Pointing Within Floors	.31**	.11	.18	-.70							
6.Sketch Map	-.25*	-.26**	-.40**	-.51**	-.62**						
7. Fact1 QOS "Survey Representation"	-.16	-.32**	-.27*	-.36**	-.29**	.40**					
8. Fact2 QOS "Compass Direction"	-.11	-.07	-.24*	-.22*	-.18	.15	-.45**				
9. Fact3 QOS "Landmark-centered"	.07	.11	-18	.22*	.12	-.28	-.10	-.13			
10. Fact4 QOS "Route-centered"	-.17	-.11	-.04	-.18	-.20	.13	.35**	.04	-.08		
11. Fact5 QOS "Visualization"	.21	-.09	.05	-.02	.12	.09	.24*	-.02	.10	.13	
12. SOD total	-.15	-.32**	-.27*	-.37**	-.27*	.33**	.86**	.54**	-.06	.37**	.18

$^{*}p < .05$; $^{**}p < .01$

Discussion

The current study aimed to investigate which subcomponents of working memory are involved in the acquisition of survey knowledge during learning by navigation in a real environment. Secondary tasks were used to investigate the contributions of verbal and spatial working memory. The main finding is that spatial secondary task interfered with encoding of survey knowledge. For all measures of survey knowledge, the interference by the spatial secondary task was greater than the interference by the verbal secondary task and for two of these measures (shortcut 2 and pointing within floors) only the spatial secondary task impaired performance relative to the control group.

Our results indicated the involvement of both subcomponents of working memory in the map completion task. Previous studies have shown a selective involvement of spatial WM in learning spatial layout from viewing a map, as measured by a sketch map task (Bosco, Longoni, & Vecchi, 2004; Coluccia, Bosco et al., 2007). The discrepancies between these studies and the present study can be attributed to a different learning source in our experiment. In map learning the view of an environment is from outside (above) the environment and the configuration of all spatial landmarks is shown simultaneously; during navigation in a real environment, the viewpoint is within the environment and landmarks are encountered sequentially. In this case, the construction of spatial representations appears to depend on the encoding of both verbal and spatial information. It should also be noted that an accurate map of an environment can be constructed from a route representation that encodes metric distances and turns (Hegarty et al., 2006). Thus the ability to draw an accurate map does not necessarily imply that the individual has encoded the environment internally as a survey representation.

We also found an effect of both verbal and spatial dual tasks in pointing judgments toward landmarks located on different floors, providing more convincing evidence of the role of verbal working memory in constructing survey knowledge. The ability to integrate landmarks on two different floors into a single integrate may be particularly demanding of cognitive resources involving verbal and spatial working memory. It is perhaps not surprising that verbal working memory was involved in maintaining spatial information, given that our experimental procedure required participants to verbally list all of the landmarks, in order, as they encountered each new landmark. Our results are consistent with those of Wen et al., (2011, 2013) who found an involvement of all subcomponents of working memory in the acquisition of survey knowledge from a video. As in Wen's (2011; 2013) tasks, in our study, to successfully complete the pointing task, one needed to compute self-to-object relations that were not directly experienced during the learning phase, suggesting that both verbal and spatial secondary tasks impaired the ability to integrate one's position with the position of the landmarks in the environment. In addition, in this study we introduced the shortcut task, which is an ecologically valid task in which participants have the same perspective as in the learning phase and use their acquired spatial information of the environment to compute an efficient route that they had not previously travelled. One possibility is that the verbal subsystem is involved in encoding and maintaining landmark and route information, and the spatial subsystem is more involved in encoding and inferring configural proprieties of an environment and planning novel routes.

To our knowledge, this is the first study that explored the role of working memory components in encoding survey knowledge in a real environment in which people move, so that they have proprioceptive and vestibular information as well as visual-spatial information. This body-based information is absent in learning from a video or (desktop) virtual environment and in map learning, and has been shown to contribute to spatial updating (e.g. Klatzky et al., 1998). Although encoding of self motion on the basis of body-based senses can facilitate the process of constructing survey knowledge of an environment, the present study indicates that spatial and verbal working memory are also important for constructing survey knowledge, even when information from body-based senses is available.

Our results are consistent with conclusions of previous studies that the ability to acquire survey knowledge is related to large individual differences in sense of direction (Ishikawa & Montello, 2006) and strategies of way-finding (e.g. Pazzaglia & De Beni, 2001).

In fact, we found a smaller error in the pointing task and better shortcuts in participants who report having a good sense of direction and prefer using a survey strategy to encode the environment, which adds to the validity of these self-report measures.

In addition, as suggested by Coluccia et al. (2004), gender differences are less consistent when people acquire spatial knowledge in real environment; in fact we found better performance of males only in Shortcut 3. However a balanced sample might reveal a clearer contribution regarding gender differences in the construction of a survey representation during navigation and this should be investigated in future research.

To summarize, our results add to the growing body of literature supporting the role of spatial and verbal working memory in learning spatial layout, and generalize these results to the learning of spatial layout from outdoor to indoor environments, and learning from media (maps and videos) to learning from direct experience walking through an environment. They also support the view that there are large individual differences in both ability to learn spatial layout and in how spatial layout is preferentially encoded, and help validate self report measures of these individual differences.

The next experiment aimed to extend the analysis of variables influencing the construction of survey representation to external factors examining, specifically, the role of the presence of landmarks.

Chapter 4

The role of individual differences and landmarks in the acquisition of survey knowledge in a virtual environment

EXPERIMENT 3

Introduction

The ability to construct an accurate survey representation is a complex process influenced by several factors. In the previous experiments we investigated the role of internal factors focusing on the role of working memory and the influence of individual differences during the acquisition of survey knowledge in navigation.

In this experiment we extended the focus on the role of external factors and specifically on the role of the presence or absence of landmarks in supporting the acquisition of spatial knowledge. Several studies (Foo et al., 2007; Foo et al., 2005; Riecke et al., 2002; Wan et al., 2012) found that humans, like honeybees, rats, primates and other animals (Gallistel, 1990), use visual landmarks to infer the global configuration of an environment. More specifically, they used classic tasks such as homing in a triangle completion (Gould & Gould, 1982) in which a participant travels two legs of an outbound path and takes the shortest route to return to the starting point (home). They showed that stable landmarks in the environment are an advantage to perform novel shortcut (Foo et al., 2005; Riecke et al., 2002), but only when people have prior knowledge about the target to reach (Wan et al., 2012). The presence of landmarks in the environment can provide important information to facilitate the navigation. Gallistel (1990) argued that animals demonstrate the possession of a cognitive map through their ability to perform novel shortcuts. In a celebrated example by Gould and Gould (1982), *home triangle paradigm*, bees are first trained to fly consistently and accurately from the hive to two feeding sites. The feeders form two legs of a triangle with the home location at the apex. Changing their home location, animals are able to take a novel shortcut from their displaced location directly to the first feeder, as evidence that they have constructed a mental map of the feeding sites by combining distance and direction information from the learned routes. Some researchers attributed successful shortcut performance to presence of salient landmarks in the environment (e.g. Dyer et al., 1993). The use of landmarks to perform novel shortcut is confirmed in humans also. Some studies showed that in the absence of visual landmarks, humans can learn two legs of a triangle with some accuracy, but performance on novel shortcuts is inaccurate and highly variable, with final position errors that are more than half of the required shortcut distance and angular deviations on the order of 30°. Shortcuts are much more accurate and precise only when stable landmarks are present (Foo et al., 2007; Foo et al., 2005; Riecke et al., 2002).

Furthermore the advantage of the landmarks might depend on some internal factors, such as the type of strategy typically used to navigate through an environment (Wan et al., 2012). In fact in Wan's study (2012), participants were asked to travel along pathway (with or without landmarks) and when they arrived at the end of the pathway, they were asked to return to either the origin or one of the landmark locations. They found no differences in learning condition with or without landmarks explaining that lack of landmark advantage might mean that participants did not use strategy based on landmarks.

Summarizing, the literature suggests that on the one hand visual landmarks can facilitate the construction of a configural representation, on the other the utility of the landmarks in the environment seems to be in relation with individual difference in sense of direction. In addition, as shown in previous researches, to construct a survey representation is required to elaborate and maintain the information in VSWM.

Given that, the aims of this study were to assess: i) the role of landmark in forming a mental representation of the environment; ii) the role of landmarks in relation to WM involvement; iii) the role of individual differences in acquiring survey knowledge and iv) how individual differences influence the construction of mental model as function of the presence/absence of landmarks.

According aim 1 (role of landmark) we expect to find an advantage in the construction of a mental representation in presence of landmarks (as suggested by Foo et al., 2005, Wan et al., 2012); participants in landmark learning condition will perform better in shortcut task compared to without landmarks learning condition (as suggested by previous studies using shortcut-like task; Foo et al., 2005, Wan et al., 2012). We will examine whether the positive role of landmark may be found also using pointing task. According aim 2 (role of landmark and WM) we examine the possible differences between presence or absence of landmark in the involvement of WM.

About the role of individual differences, first of all, we followed steps below:

a) we individuated the spatial individual factors (using factor analysis approach)

b) we computed the measure able to predict the acquisition of mental representation (using correlations and regression models approach). According aim 3 (role of individual differences) we expect to find that people with high sense of direction and preferring survey strategy in orientation task construct more accurate mental model of the environment than lower sense of direction ones (as suggested by Ishikawa & Montello, 2006; Wen et al., 2011).

According aim 4 (relationship between individual differences and landmarks) we expect that the ability to successful perform survey tasks in an environment without landmarks, depends on individual differences in sense of direction and the use of survey strategy during navigation.

Method

Participants

A total of 132 (66 males) students of University of Padua took part to the study (Mean age = 23.6, SD = 2.11). They were assigned to one of two groups: 60 learned the route in an environment with landmarks distinguished 20 (males 10, females 10) in C, 20 (males 10, females) in ST, 20 (males 10, females 10) in AS groups, 72 learned the route in an environment without landmarks 23 (males , females 12) in C, 25 (males 11, females 14) in ST, 24 (males 12, females 12) in AS.

Materials

Individual Differences Measure

Working memory measures

We used Corsi and Digit Span Forward and Backward (for details description see Chapter 2)

In addition we used:

- Spatial Anxiety Scale (SAS, Lawton, 1994)
- Object-Spatial Imagery Questionnaire (OSIQ, Blajenkova et al., 2005)
- Questionnaire on Attitude towards orientation tasks (Pazzaglia et al., 2004)
- Auto-efficacy Scale (adapted by Lawton, 1994)
- Santa Barbara Sense of Direction Scale (SBSOD, Hegarty et al., 2002)
- Questionnaire on Spatial Representation (QOS, Pazzaglia et al. 2000).

For all details about individual measures see Chapter 2.

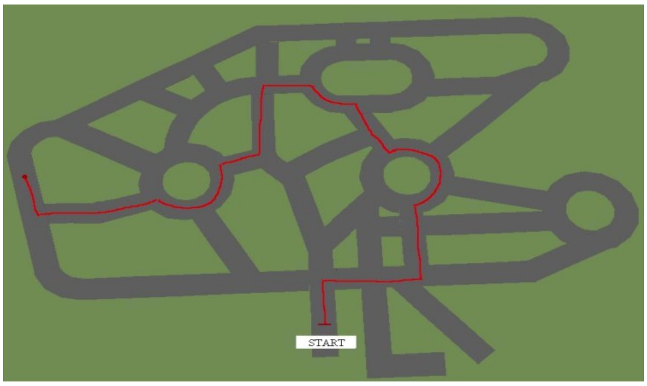
Virtual environment

Same environment with landmarks described in experiment 1, was used for this experiment.

In the Figure 4.1. – panel a - is presented the path in the environment with landmarks and in figure 4.1 – panel b- the environment without landmarks.

Panel 4.1.a – Virtual environment view with landmarks -

Panel 4.1. b – Virtual environment without landmarks



Secondary tasks

As in previous experiments spatial tapping task (ST) and articulatory suppression task (AS) were used.

Shortcut Task

The task consists to travel in the virtual environment finding the shortest route between start and end-point of the route travelled by avatar. For moving forward, backward, right, left was necessary to use a joystick. Correct shortcut is depicted in Figure 4.2.

Figure 4.2 Correct Shortcut of 128 cm measured on the map of the environment.

Pointing Task

Pointing task consists to indicate the direction of the end point respect to starting point. The response was given using a circle (diameter about 4 inches) with a vertical arrow departing from the center and intersecting the circle on the upper part. The arrow designated the imagined facing direction and indicated the start point of the route travelled by avatar. The task consists to draw a second arrow from the center to the boundary, indicating the direction of end point.

Procedure

Participants were individually tested in single session for about 90 minutes.

Participants, in the first phase, filled out the questionnaires in the follow order: Questionnaire on Spatial Representation, Spatial Anxiety Scale, Object-Spatial Imagery Questionnaire, Questionnaire on Attitude towards Orientation tasks, Auto-efficacy Scale, Santa Barbara Sense of Direction Scale, Corsi Blocks task and Digit Span task.

After that, participants familiarized with virtual reality moving, through the joystick, in a sample virtual environment for 5 minutes. Successively participants in learning condition with landmarks, learned the route travelled by an avatar in an environment characterized by the presence of landmarks. Participants in learning condition without landmarks, learned the route travelled by an avatar in an environment without landmarks.

Participants in the secondary task conditions first practiced the secondary task alone for 30 seconds. Participants in the AS condition were instructed to say the syllables ba-be-bi-bo-bu at a rate of one syllable per second. Participants in the ST condition were instructed to tap four keys in a specific pattern on the board at the rate of one tap per second, without looking at the tapping board. After that, each participants learned the route performing the concurrent task. In control condition no dual task was performed during navigation.

Then participants were asked to find the shortcut to reach the endpoint of the route travelled by avatar and to perform pointing task. In the shortcut task, participants travelled in the environment through the joystick. The task finished when they arrived at the end point. Experimenter, watching the registration of the route travelled by participants, traced on a map of the environment the path travelled measuring its length in cm.

Finally participants completed the pointing task, where they were told to imagine standing at the starting point of the route and to indicate the position of the end-point drawing an arrow.

Results

Scoring

- For shortcut it was relieved the length of the route travelled by participant to reach the end-point. The error of length of the shortcut was calculated subtracting the length of shortcut travelled by participants from the length of actual shortcut (128 cm on the map).
- For pointing task it was considered the error-pointing between correct position and position that participant pointed.

Shortcut Task

An analysis of variance (ANOVA) 3 (dual task: ST vs AS vs CO) x 2 (landmark: with vs without landmark) with gender as a covariate variable (given that it role in environment learning is relevant, Lawton, 1994) was carried out. The results showed only the main effect of landmark factor $F(1,123) = 24.18$, $p < .001$, $\eta^2_p = .18$. Post hoc showed that when participants learned the route without landmarks (M= 236.88, SD = 255.96), they performed shortcut longer than participants learned with landmarks (M = 60.85, SD = 94.21). No other main effects or interaction were found (C: M = 159.93, SD = 271.06; ST = 122.05; SD = 168.20; AS: M = 178.15; SD =193.59).

Pointing Task

An analysis of variance 3 (dual task: ST vs AS vs CO) x 2 (landmark: with vs without landmark) with gender as a covariate variable showed no significant effects or interactions. Participants that learned the route with landmarks (M = 54.42, SD = 54.84) performed pointing task like participants learned without landmarks (M = 70.32, SD = 55.24), and no significant differences between interference groups (C: M = 62.40, SD 52.49; ST: M = 63.44, SD = 56.21; AS: M = 63.41, SD = 58.59).

Individuation of spatial individual factors

In a preliminary factor analysis on questionnaires on sense of direction, strategies used in navigation and spatial-imagery ability in everyday life (QOS, SBSOD and Spatial-Imagery Scale (OSIQ) we found that items of Spatial Imagery Scale (OSI) not saturated in any component with items of the other two questionnaires.

Given that, we carried out one factors analysis on QOS and SBSOD to extract a factor about sense of direction and survey strategy that literature shown are successfully factors in orientation tasks. Analysis of screen plot showed that after the first 6 factors the slope flattened, so we chose to extract 6 factors that explained 15 %, 10%, 10%, 9%, 7%, 6% (56 % total) of variance respectively.

When examining the rotated factor pattern, an item was considered to load on a factor if the given loading was greater than 0.40 (see table 4.1). The factor 1 include items 1, 2, 3c of QOS and

1, 3, 4 and 10, 11 and 14 of SBSOD about survey strategy and sense of direction. The factor 2 include items 6, 7, 8, 9, 12, 13 and 15 of SBSOD about the use of map strategy; Factor 3 is composed by 5, 6 and 10 of QOS and item 5 of SBSOD about the use of cardinal points; Factor 4: 4a, 8, 9 and 11 of QOS about the ability to orient in the building; Factor 5 include item 3a, 3b, 4b and 4c of QOS about the use of route strategy; Factor 6 is composed by items 7a and 7b about the ability to use imaginative strategy.

Table 4.1 Factors individuated by Factorial Analysis on QOS and SBSOD.

	1	2	3	4	5	6
QOS1.Do you think you have a good sense of direction?	.70					
QOS2.Are you considered by your family or friends to have a good sense of direction?	.63					
QOS3.Think about the way you orient yourself in different environments around you. Would you describe yourself as a person: a. who orients him/herself by remembering routes connecting one place to another.					.40	
QOS3b.who orients him/herself by looking for well-known landmarks.					.69	
QOS3c.who tries to create a mental map of the environment	.42					
QOS4a. Think of an unfamiliar city. Write the name……Now try to classify your representation of the city: survey representation, that is a map-like representation				.52		
QOS4b. route representation, based on memorizing routes					.77	
QOS4c. landmark-centered representation, based on memorizing single salient landmarks (such as monuments, buildings, crossroads, etc.)					.75	
QOS5.When you are in a natural, open environment (mountains, seaside, country) do you naturally individuate cardinal points, that is where north, south, east and west are?			.83			
QOS6.When you are in your city do you naturally individuate cardinal points, that is do you find easily where north, south, east and west are?			.69			
QOS7a. Someone is describing for you the route to reach an unfamiliar place. Do you prefer: to make an image of the route						.70
QOS7b. to remember the description verbally						-.81
QOS8. In a complex building (store, museum) do you think spontaneously and easily about your direction in relation to the general structure of the building and the external environment?				.72		
QOS9.When you are inside a building can you easily visualize what there is outside the building in the direction you are looking?				.76		
QOS10.When you are in an open space and you are required to indicate a compass direction (north-south-east-west), can you point immediately?			.75			
QOS11.You are in a complex building (many floors, stairs, corridors) and you have to indicate where the entrance is, can you (circle one) indicate immediately it?				.58		
	1	**2**	**3**	**4**	**5**	**6**

SBSOD1.I am very good at giving direction	.74					
SBSOD2.I have a poor memory for where I left things						
SBSOD3.I am very good at judging distances	.47					
SBSOD4.My sense of direction is very good	.80					
SBSOD5.I tend to think at my environment in terms of cardinal direction			.56			
SBSOD6.I very easily get lost in a new city		.50				
SBSOD7.I enjoy reading maps		.60				
SBSOD8.I have trouble understanding directions		.55				
SBSOD9.I am very good at reading maps		.61				
SBSOD10.I don’t remember routes very well while riding as a passenger in a car	.65					
SBSOD11.I don’t enjoy giving a directions	.54					
SBSOD12.It’s not important to me to know where I am		.65				
SBSOD13.I usually let someone else do the navigational planning for long trips		.67				
SBSOD14.I can usually remember a new route after I have traveled it only once	.53					
SBSOD15.I don’t have very good mental map of my environment		.51				
	1	**2**	**3**	**4**	**5**	**6**

Correlations

Correlations between dependent variables (Error shortcut –length, pointing direction –error) and measures of individual differences, split per learning condition with (Table 4.2. a) and without landmarks (Table 4.2.b)

Table 4.2.a. Correlation between dependent variables and individual differences in learning condition with landmarks

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.Shortcut	1															
2.Pointing	.20	1														
3.Digit Farward	.11	-.08	1													
4.Digit Backward	-.13	-.15	.37*	1												
5.Corsi Farwward	.10	-.08	-.18	-.01	1											
6.Corsi Backward	-.12	-.20	-.15	.20	.44**	1										
7.Factor1	-.28*	-.14	.09	-.01	.14	.04	1									
8.Factor2	-.29*	-.14	.02	-.21	.02	-.10	.71**	1								
9.Factor3	-.04	-.06	.01	.07	.25	.06	.54**	.37**	1							
10.Factor4	-.15	-.34**	.07	.06	.19	.16	.52**	.47**	.47**	1						
11.Factor5	-.09	-.13	-.29*	-.21	.33**	.28*	.17	.08	.09	-.02	1					
12.Factor6	-.07	-.27*	.02	.07	.23	.34	.02	-.08	.09	.11	.34**	1				
13.Spatial Anxiety Scale	.12	.20*	-.08	-.03	.07	-.09	-.51**	-.32*	-.17	-.33*	.12	.06	1			
14.Spatial Scale	-.01	-.15	.14	.14	.20	.00	.40**	.37**	.43**	.32*	-.20	-.07	.02	1		
15.Object Scale	-.09	.15	-.34**	-.08	.10	.20	.23	.10	.08	.20	.23	.03	-.07	-.08	1	
16.Attitude	-.13	-.01	-.02	.05	.27*	.04	.74**	.64**	.56**	.51**	.09	-.06	-.34**	.44**	.28*	1
17.Autoefficacy	-.18	-.17	.15	.07	.03	.06	.75**	.58**	.46**	.60**	-.01	.08	-.71**	.28*	.18	.56**

Table 4. 2.b. Correlation between dependent variables and individual differences in learning condition without landmarks

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.Shortcut	1															
2.Pointing	.08	1														
3.Digit Farward	-.01	-.06	1													
4.Digit Backward	.03	-.16	.48**	1												
5.Corsi Farward	-.10	-.14	.08	.09	1											
6.Corsi Backward	.02	-.08	.01	.18	.28*	1										
7.Factor1	-.32*	-.14	.03	.05	-.03	-.10	1									
8.Factor2	-.24	-.14	-.04	-.04	.01	-.15	.54**	1								
9.Factor3	-.10	.02	.21	.01	.04	.01	.30**	.29*	1							
10.Factor4	-.09	-.08	.00	-.06	-.13	.03	.49**	.27*	.35**	1						
11.Factor5	-.17	-.07	-.01	-.12	-.03	-.10	.05	-.11	.08	.11	1					
12.Factor6	-.04	.01	.08	-.14	-.18	.00	.17	.13	.34**	.28*	.17	1				
13.Spatial Anxiety	.19	.04	.19	.08	-.12	.21	-.39**	-.39**	-.20	-.16	-.04	-.13	1			
14.Spatial Scale	-.08	-.07	.17	.17	.21	.23	.31**	.17	.34**	.05	-.07	-.08	.00	1		
15.Object Scale	.01	.07	-.09	-.03	-.17	-.11	.06	.12	.15	.21	.08	.28*	-.13	-.44**	1	
16.Attitude	-.27	.03	-.01	-.06	-.05	-.12	.56**	.51**	.44**	.34**	.16	.07	-.29*	.27*	.07	1
17.Autoefficay	-.19	.11	-.01	-.08	-.12	-.21	.51**	.45**	.36**	.32**	.10	.17	-.32**	.18	.09	.74**

Results showed that the shortcut correlated negatively with sense of direction Factor 1 (QOS_SBQ) in both learning conditions (with landmarks: $R = -.28$, $p = .03$; without landmarks: $R = -.31$, $p = .01$) showing that high survey ability correlate with shorter route in shortcut task . In addition, in learning condition with landmarks, shortcut performance correlated negatively with Factor 2 (QOS_SBQ) ($R = -.29$, $p = .03$) indicating that the ability to use a map correlates with ability to find a shortcut, while in learning condition without landmarks correlated negatively.

Pointing performance showed some correlations only in learning condition with landmarks. Specifically correlated negatively with Factor 4(QOS_SBQ) ($R = -.34$, $p = .007$) and 6 (QOS_SBQ) ($R = -.27$, $p = .03$) showing that less ability to orient in a building and the preference to use verbal strategy correlate with higher error pointing.

Predictive role of spatial individual factor on environment survey measure

Regression models were used to investigate if the individual differences measures could differently predict the performance on shortcut task as a function of type of learning condition (landmark vs. without landmarks). Initially, the main predictors were selected using a stepwise regression, inserting shortcut performance as the dependent variable, and the measures significantly correlated with shortcut task as independent variable (Factor 1 and 2 about sense of direction and the preference to use map strategy respectively). The results showed that the measure selected was Factor 1 ($R^2 = .06$, $F = 8.30$, $p = .005$, $\beta = -.25$).

Then a hierarchical multiple regression was used to analyze how the influence of the sense of direction change as a function of the presence/absence of landmarks in the environment during learning of a route.

At a first step in the regression, the two experimental learning conditions (a dichotomous variable, i.e., 1 for learning condition with landmarks and 0 for learning condition without landmarks) were inserted as independent variables. At a second step the value of Factor 1 (QOS_SBQ) (survey ability).

At third step, the values corresponding to the interactions between the each experimental condition (learning with/without landmarks) and Factor 1 (QOS_SBQ) was considered as independent variables.

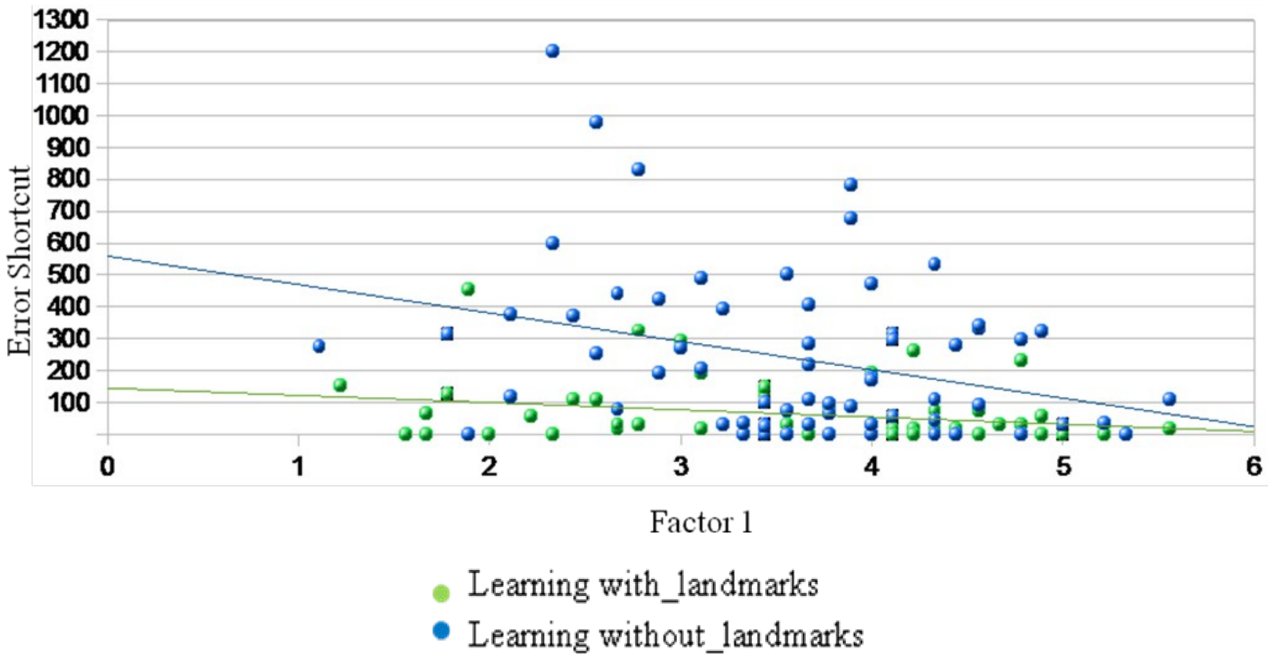
The hierarchical regression analysis showed at the first step the main effect Learning Condition ($R = .17$, $F(1,122) = 24.84$, $p \leq .001$) and in the second step the main effect of Factor (QOS_SBQ) ($R = .06$, $F(1,121) = 8.80$, $p = .004$), accounting for 23 % of the variance.

The third step showed the significant interactions Learning Condition X Factor 1(QOS_SBQ) ($F(1,120) = 3.98$, $p = .04$) (see table 4.3). Slope analysis showed that Factor 1 (QOS_SBQ) influenced more the performance in the learning condition without landmarks ($R^2 = .10$) than learning condition with landmarks ($R^2 = .08$) (see figure 1), indicating that people with low survey ability travelled longer shortcut in the environment without landmarks compared to people with high survey ability.

Table 4.3 Hierarchical multiple regression on shortcut length

	Predictors	ΔR^2	β	t	p
Step 1	Learning Condition (Land_noLand)	.17, $p \leq .001$	-.41	- 4.98	$p \leq .001$
Step2	Factor1	.06, $p = .004$	-.24	- 2.97	$p = .004$
Step 3	Learning Condition x Factor1	.03, $p = .048$	.63	1.99	$p = .048$

Figure 4.3 Slope analysis hierarchical multiple regression on shortcut length



Discussion

The current study aimed to investigate how external factors such as presence of landmarks and internal factors, such as individual difference in sense of direction and working memory, can interact influencing the acquisition of survey knowledge in a virtual environment. The main finding is that in the acquisition of survey knowledge in a virtual environment play a key role the individual differences and the ability to use survey strategy during navigation.

In according with our hypotheses we found an advantage of the presence of landmarks in the forming of a survey representation during navigation in a virtual environment (aim i) and better performance of people with high sense of direction (aim iii).

As in experiment 1, we did not find the involvement of working memory (aim ii). This result confirmed that the acquisition of survey knowledge in an virtual environment, in which vestibular and proprioceptive information are absent and the interaction with environment is not completely immersive, might involve more individual differences than cognitive processes.

According to literature (Foo et al., 2005, Wan et al., 2012), we confirmed that the construction of survey representation is better in the learning condition with landmarks, showing that people, as animals, are more able to infer a global configuration when landmarks are available in the environment.

The results of hierarchical regression (aim iv) are interesting. They showed that in absence of landmarks, the construction of survey knowledge depends on individual difference in the ability to use survey strategy in orientation task. . This study added to the growing body of literature that the sense of direction is the predictor of the construction of survey representation in an environment without landmarks.

To our knowledge, the present study is the first to show how individual differences and the availability of landmarks in a virtual environment can interact in the building up of a mental representation.

Chapter 5.

Influence of route and survey instructions and the involvement of working memory in the acquisition of spatial knowledge during navigation in a virtual environment

EXPERIMENT 4

Introduction

In this experiment we extended the analyses of external factors influencing the process of the construction of spatial representation to the role of instructions. The instructions about the task to perform after navigation, can influence navigation behaviour.

Previous studies showed that both in map learning (Taylor et al., 1999) and in navigation learning (Magliano et al., 1995) there is an effect of the instruction: route instruction, such as "your task is to learn a route in the environment", guide the attention on route elements leading to a better construction of route representation, while survey instruction, such as "your task is to learn the layout of the environment", guide the attention on survey elements leading to better construction of survey representation.

In Taylor et al.'s study (1999), participants studied the map focusing on different elements of the map as function of received instruction. Participants with survey instructions increased performance on allocentric tasks such as Euclidian distance estimation, whereas participants with route goal increased performance on egocentric task such as route distance estimation. Brunye and Taylor (2009) through using ocular movements confirmed that different instructions take the attention on specific part of the map. With survey instruction, eye movements are focused towards compass coordinates. Route instruction, in contrast, biases attention towards the streets and street names.

In a real-world navigational task Magliano et al. (1995), confirming developmental studies (Gauvian & Rogoff, 1986), showed that adults received survey instruction performed better in survey tasks compared to participants with route instruction.

However Pazzaglia and Taylor (2007), in a virtual navigational study, did not confirm the effect of the instruction. Participants with high and low preferences for survey representations learned a route in an urban virtual environment from a map ("survey" perspective) or from virtual navigation ("route"), with instructions to focus either on landmarks or on intersections. Their manipulation in focusing participant attention on either landmarks or intersections did not produce effects, probably because participants even though attentive to directions, adopted spontaneous learning strategies they considered more efficient considering their preference and the characteristics of the material.

This study suggested that the effect of the instruction could be related to individual differences. Saucier, Green, Leason, MacFadden, Bell, et al., (2002) reported that the instruction modulate gender differences in navigation tasks. When participants received landmark instructions (e.g., turn right at the bridge) to use for navigation, no sex differences were found; whereas the typical male advantage appeared when participants were given instructions that were based on the Euclidean features of the environment (e.g., go 100m and then turn north).

Summarizing these study suggested on the hand that the instructions influence the construction of spatial representation , on the other that the effect of instructions can be modulate by individual differences. However remain to answer whether different instructions influence also the involvement of different cognitive resource.

To our knowledge only one study investigated the relation between instruction and cognitive processes. Saucier, Bowman, & Elias (2003) in a navigational matrix study, investigated the effect of instructions on the involvement of working memory in navigation task, using dual task paradigm, in relation to gender differences. They used a matrix in which were iconic representations of ten highly frequent English nouns and appeared 10 times within the matrix. Participants during navigation performed either articulatory suppression or spatial tapping. While navigating they read landmark or euclidean instructions. They showed that articulatory suppression significantly impaired the performance of women who followed landmarks and also euclidean-based instructions. No interference of spatial tapping was found on man performance regardless of instruction. They supposed that the lack of effect of spatial interference may be related to the relative ease of the navigation task.

In this study was investigated the relation between route and survey instructions and the involvement of working memory in the construction of route and survey representation during navigation in a virtual environment. Participants received route or survey instructions and then navigated in a virtual environment performing the dual task (as in our previous studies). After navigation participants performed retracing route, shortcut task and drawing map.

Method

Participants

Ninety undergraduate students at the University of Padua, participated in the study. They were assigned to one of two groups: 45 (females 24, males 21) received route instructions, 45 received survey instructions (females 22, males 23). In each group: 15 performed the learning route with the articulatory suppression task (AS), 15 performed the learning route with the spatial tapping task (ST), and 15 performed the learning route alone, with no dual task, control group (C).

Individual Differences Measure

Working memory measures:

-*Reading Span Test* (adopted from Daneman & Carpenter, 1980)

The task consists of an increasing number of 2, 3, 4, 5,6 sequences of simple sentences. The sequences are grouped into 4 sets composed of four sequences each. For each set, 20 sentences are presented (giving a total of 80 sentences), each separated from the subsequent sentence by an interval of 1.5 seconds. Participants are instructed to read each sentence, judge its plausibility (state whether it is true or false) and retain the last word. At the end of each set, participants are required to recall the final words following the correct order of presentation. Two training trials precede the task. The total number of final words correctly recalled in the correct order during the whole test is considered the measures of the participant's working memory capacity.

-*Dot Matrix task* (derived from Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001)

The task consists to check a matrix equation while simultaneously remembering a dot's location in a 5x5 matrix. A trial involves a set of matrix equations to check, each followed by a 5x5 matrix containing one dot. The matrix equation paper shows a simple addition or subtraction equation. Participants were given 4,5 seconds to check whether the result of adding (or subtracting) two segments presented in succession corresponded to a third pattern presented after the previous two. Immediately afterwards, a 5x5 matrix containing a dot in one cell was displayed on the screen for 1,5 seconds. After a series of 2-5 equations and matrices had been presented, participants had to recall (in any order) which cell in the 5x5 matrix had contained dots (by indicating in the empty cells with the bottons).

-*Corsi Blocks task* (Corsi, 1972) and *Digit Span task* (Wechsler, 1981) (for details description see Chapter 2)

Individual differences orientation ability

Were used same measures of individual difference in orientation tasks of previous experiment (for description see Chapter 2):

a.Spatial Anxiety Scale (SAS, Lawton, 1994)

b. Questionnaire on Attitude towards oreintation tasks (Pazzaglia, Poli, & De Beni, 2004)

c.Auto-efficacy Scale (adapted by Lawton, 1994)

d.Santa Barbara Sense of Direction Scale (SBSOD, Hegarty, et al., 2002)

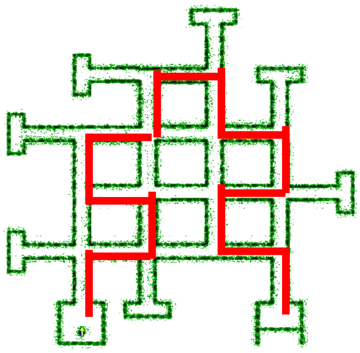
e.Questionnaire on Spatial Representation (QOS, Pazzaglia et al., 2000)

Virtual environment

We used a virtual urban environment, programmed in Virtools software. Information was displayed visually on a computer monitor. The interaction with the environment was controlled through a joystick.

The path, as in previous studies in virtual environment, was presented in route perspective in which the participants followed, watching the monitor, a specific route. The route, 184 meters long, composed of 15 segments that included 14 turns (8 on the right and 6 on the left). Specifically a segment was defined as the unit of route between two adjacent nodes. The environment contained a 10 landmarks (bench, fountain, basket, plant, fire extinguisher, sign, street lamp, scale, world-map, shovel), distributed 5 along the segments and 5 in cross points. In the Figure 5.1 is presented the map of route in the environment.

Figure 5.1 Map of virtual environment



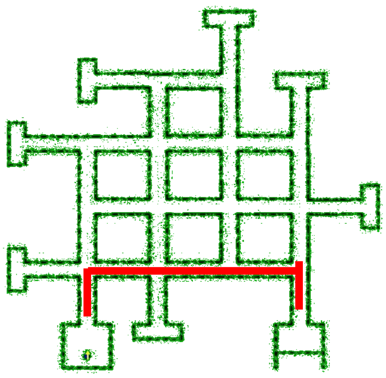
Secondary tasks

Spatial Tapping Task (ST) and Articulatory Suppression Task (AS) were used to overload spatial and verbal working memory respectively (see description in Chapter 2).

Shortcut Task

The task consists to travel in the virtual environment finding the shortest route between start and end-point of the route travelled by avatar. For moving forward, backward, right, left was necessary to use a joystick. Correct shortcut is depicted in Figure 5.2.

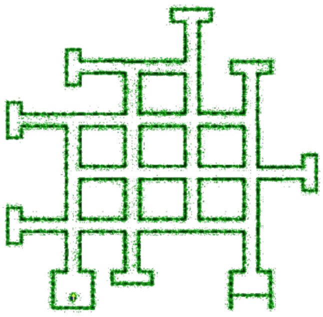
Figure 5.2 Correct Shortcut of 62 meters.



Completion Map

Completion map task consists to complete the map of the environment (figure 5.3) given to participants in a sheet of paper, placing the landmarks in their correct position and drawing the route that participants travelled in virtual environment.

Figure 5.3 Schematic map of the environment given to participants in a sheet of paper.



Procedure

Participants were tested in single session for about 90 minutes.

Participants, in the first session, filled out the questionnaires. Before starting experimental session participants completed familiarization session in which they move in a sample virtual environment for 5 minutes. Then in learning phase were instructed to learn the path observing the route, as they moved in first person in the virtual environment.

Participants were randomly assigned in one of two condition: route or survey instructions. In route condition participants were told to observe the route because after that they had to retrace it. In survey condition, participants were told to observe the route because after that they had to travel the shortest route between the start and to the end-point. In each participants were assigned to one of the three dual task condition (ST, AS, C). Participants in the secondary task conditions first practiced the secondary task alone for 30 seconds and this served as the measure of baseline (single task) performance of the secondary tasks. Participants in the AS condition were instructed to say the syllables ba-be-bi-bo-bu at a rate of one syllable per second. Participants in the ST condition were instructed to tap four keys in a specified pattern on an a board at the rate of one tap per second, without looking at the tapping board.

During learning phase, participants assigned in ST during watching the video illustrating the path they tapped the botton of the board at the end of the route travelled by avatar. Participants assigned in AS during path presentation they repeated the continuously repeated the syllables . In control condition no dual task was performed and participants watched the video of the path.

After learning session it was followed by testing phase performing in balanced order the retracing route and the shortcut. In retracing route was request to retrace learned route in the virtual environment. When participants took wrong direction, they saw on the desktop “wrong direction”. In shortcut was request to travel in the virtual environment finding the shortest route to reach the end point of the route travelled by avatar. The task finished when they arrived at the end point.

Finally they completed completion map, where they given a paper with schematic map of the environment and they were told to collocate landmarks in their correct position and route shown in learning session.

Results

Scoring

For retracing route were calculated the number of errors to reach the end-point.

For shortcut it was relieved the length of the route travelled by participant to reach the end-point. We calculated the error of length of the shortcut subtracting the length of shortcut travelled by participants from the length of actual shortcut (62m).

For completion map was consider the number of landmark correctly placed and the number of correct segments drawn in the map.

Measures of Spatial Learning

To examine the effects of the secondary task on spatial learning we conducted a number of analyses of variance (ANOVAs) with type of interference (control, verbal, and spatial), type of instructions (route, survey) and gender (male, female) as a between subject factors on the following dependent measures: number of errors, length of the shortcut and completion map.

Retracing route

Analysis of variance (ANOVA) on errors during retracing route showed an effect of type of instructions ($F_{(1,89)} = 8.10$; $p = .006$; $\eta^2p = .09$). Post-hoc comparisons (Least Significant Differences Test, LSD) indicated that survey group (M = 1.74; SD = 1.63) performed significantly higher error than route group (M = 3.00; SD = 2.36). Results revealed, also, an effect of gender ($F_{(1,89)} = 5.37$;($p = .02$) ; $\eta^2p = .06$) with female (M= 2.87; SD = 1.87) reported more errors than males (M = 1.89; SD = 2.22).

Shortcut Task

Analysis of variance (ANOVA) on error shortcut showed an effect of type of instructions ($F_{(1,89)} = 8.38$; $p = .005$; $\eta^2p = .10$). Post-hoc comparisons (Least Significant Differences Test, LSD) indicated that route group (M = 161; SD = 129) performed significantly longer shortcut than survey group (M = 86; SD = 109). Results revealed, also, an effect of gender ($F_{(1,89)} = 9.19$;($p = .003$) ; $\eta^2p = .10$) with female (M= 161; SD = 136) reported longer shortcut compared to males (M = 76; SD = 94). No other differences were found (all $p_s > .05$).

Completion Map

Analysis of variance (ANOVA) on landmark correctly placed on the map showed only an effect of gender ($F_{(1,89)} = 10.81$; $p = .002$; $\eta^2p = .12$) with female ($M= 1.61$; $SD = 1.37$) reported fewer landmark in their correct position compared to males ($M = 2.95$; $SD = 2.18$).

Analysis of variance (ANOVA) on correct segments of route drawn in the map showed an effect of type of interference ($F_{(2,88)} = 3.46$; $p = .03$; $\eta^2p = .08$). Post-hoc comparisons (Least Significant Differences Test, LSD) indicated that participants in spatial dual task condition ($M = 11.73$, $SD = 3.39$) reported fewer segments of correct route ($M = 13.70$, $SD = 2.30$). No other difference between groups were found (AS: $M = 12.37$; $SD = 4.10$; ($p_s > .05$).

Results revealed, also, an interaction type of interference X type of instructions ($F_{(2,88)} = 4.36$; $p = .01$; $\eta^2p = .10$). Post hoc showed that in spatial dual task condition participants with route instruction reported fewer segments than those with survey instruction ($p = .02$) (see table 5.1).

Table 5.1 Completion Map – Means and standard deviations of segments drawn in map –

Group	Instruction	Segments of route drawn in map
Articulatory Suppression	Route	12 (3.5)
	Survey	11(5.5)
Spatial Tapping	Route	10.33 (3.8)
	Survey	13.13 (2.26)
Control	Route	14.13 (1.77)
	Survey	13.27 (2.74)

Individual differences

We examined the role of individual differences in retracing route, shortcut and completion map, correlating the performance with measures of individual differences.

Errors in retracing route correlated negatively with Digit Backward ($r = -.21$, $p = .04$), Corsi Forward and Backward, indicating that having a poorer verbal and spatial working memory span corresponded to poorer performance on retracing learned route (Corsi Forward: $r = -.34$, $p = .001$) Corsi Backward: $r = -34$, $p = .001$).

Shortcut task correlated negatively with survey strategy of QOS and sense of direction (Factor 1 of QOS) indicating that low survey strategy ($r = -.22$, $p = .03$) and sense of direction ($r = -.27$, $p = .01$) corresponded to minor ability to integrate the information of the environment leading worse shortcut. Performance in shortcut task correlated negatively, also, with sense of auto-efficacy showing that low sense of auto-efficacy lead worse performance in shortcut task ($r = -.21$, $p = .04$)

Finally completion map showed negative correlation with Corsi Backword an survey strategy. More specifically participants with high survey strategy and ($r = .27$, $p = . 10$) high span in Corsi Backward ($r = -.30$, $p = .004$) placed more landmarks in correct position and drawn more segments (Corsi Backward: $r = -.23$, $p = .02$) of the route on the map.

Discussion

The current study aimed to investigate the relation between the instructions and the involvement of subcomponents of working memory in the acquisition of route and survey knowledge in a virtual environment. As in previous experiments, we used secondary tasks to investigate the contributions of verbal and spatial working memory. The main finding is that the instructions played a main role in the way in which people encoded and integrated spatial information in a spatial representation. According to previous studies (Taylor et al., 1999; Magliano et al., 1995) subjects with survey instructions (after learning you should find the shortest route between start to end point) were better in shortcut task than retracing route while people with route instructions (after learning you should retrace the route again) were better in retracing route compared to shortcut tasks.

The results about completion map are more interesting. Specifically, in drawing route in the map, spatial secondary task interfered with performance. It is interesting that retracing route did not show the involvement of working memory while the same task in other dimension, such as the map, produced lower performance.

An interpretation could be that completion map, being the unique task in which there is a different perspective compared to the learning perspective, may be particularly demanding of cognitive resources involving spatial working memory. In fact, in Brunye et al. s' study (2009), people studied the map with route goal, performed better on egocentric perspective statements whereas people studied the map with survey goal performed better on allocentric perspective statements, supporting that there are better performance when there is the same perspective between learning and recall phase.

In addition our results showed that the interference effect of spatial dual task in the acquisition of spatial knowledge was lower if participants received survey instruction respect to participants with route instructions. The results seem to suggest that the instructions preparing to acquire specific spatial knowledge, follow to focus the attention on specific elements in the environment, leading to stronger spatial representation.

Not minor important is the role of gender. According to literature, we found that females were less able in all tasks compared to males (Coluccia, 2004). In contrast to Saucier et al., (Saucier et al., 2002; Saucier et al., 2003) in our study females did not take an advantage with route instructions. However while in Saucier's studies participants read instructions while navigated, in our experiment, participants received instruction before the learning phase. Therefore, probably, the strategies used by females, even with route instructions, were not sufficient to complete efficiently navigation tasks and completion map.

Individual difference measures confirmed, as in previous experiments, that in the acquisition of route knowledge, play a key role individual measure of working memory, while in the acquisition of survey knowledge play a key role the strategies (Hegarty et al., 2006; Wen et al., 2011, 2013) and sense of auto-efficacy, confirming that the construction of survey representation is more sensitive to individual differences.

To our knowledge, this is the first study that explored the relation between instructions and working memory in the encoding of route and survey knowledge. However, considering the small sample, it is necessary to investigate this aim more deeply. Our results suggested that, the instructions guide the process of the construction of a spatial representation (Taylor et al., 1999; Magliano et al., 1995) influencing , also, the involvement of cognitive resources.

General conclusions

The general aim of this dissertation was to understand which factors are involved in the construction of a spatial representation during navigation. We focused on the involvement of working memory analyzing, through dual task paradigm, how verbal and spatial working memory influence the construction of route and survey representation during navigation.

Until now, research carried out to date on spatial representation has looked at the role of verbal (VWM) and visuo-spatial (VSWM) working memory in the construction of route representation during navigation (Garden et al., 2002; Meilinguer et al., 2008). However, the role of working memory in the construction of survey representation during navigation had not been directly investigated.

In particular this research focused on the analysis of:

1.VWM and VSWM involvement in the construction of route and survey representation during navigation in virtual environment (Experiment 1)

2. Role of VWM and VSWM involvement and individual differences in the construction of survey representation during navigation in real environment (Experiment 2)

3.Analysis of the predictors of the construction of survey representation: role of landmarks and individual differences and working memory in the construction of survey representation during navigation in virtual environment (Experiment 3).

4.Influence of the instructions and VWM and VSWM in the construction of route and survey representation (Experiment 4).

In all of the experiments dual task paradigm was used. Participants learnt a route in a virtual (Experiments 1,2,4,) or real (Experiment 3) environment performing spatial or verbal secondary task simultaneously. Reproduction of the route, pointing task, drawing map and shortcut tasks were used to investigate the construction of route and survey representation during navigation. Particularly interesting for this project of research was the performance of shortcut task.

In fact, in previous studies the acquisition of survey knowledge has been measured using performance on map drawing tasks and pointing to unseen landmarks. Both of these tasks, can be completed on the basis of survey knowledge (Richardson et al., 1999).

In our studies we even introduced finding shortcut, a task in which there is the same perspective of learning phase and where the use of both a ego-centered system (to navigate in the environment) and a configurational representation (to individuate the shortest route) are necessary (Golledge, 1999).

Regarding the first point, Experiment 1 was aimed to investigate the contribution of VWM and VSWM in the construction of route and survey representation during learning of a route in a virtual environment, examining the performance on retracing route and shortcut tasks. The results confirmed, in according to literature (Garden et al., 2002, Meilinguer et al., 2008), that overloading VWM and VSWM impair the construction of route knowledge leading to low performance on retracing route. Shortcut task was impaired by spatial dual task only in females performance probably because, as suggested by Coluccia et al., (2007), gender differences are pronounced when the task requires VSWM. The lack of the main effect of spatial dual task on the performance in finding shortcut opened many questions about the factors that could be involved in the construction of survey representation.

In Experiment 2 and 3 the focus was restricted to the acquisition of survey knowledge analyzing the role of internal and external factors. Recently some frameworks, about the process of acquisition of spatial knowledge, suggested that the acquisition of survey knowledge is not a final step of a progressive spatial process, but the development depends on several factors such as individual differences in the sense of direction (Montello's framework, 1999), in the way to interact with the environment (e.g. sense of anxiety) (Kitchin's model,

1996) and in the ability to maintain spatial information in working memory in a configural representation (Hegarty et al., 2006).

In Experiment 2 we analyzed the role of WM and individual differences in the acquisition of survey knowledge during navigation in a real environment. The main results of Experiment 2 showed that participants learned a route in real environment performing simultaneously spatial tapping, performed longer shortcut and worse performance on pointing tasks than participants in control condition. In addition, as suggested by previous studies (Pazzaglia et al., 2000; Hegarty et al., 2006), better performance in survey tasks were correlated with high sense of direction and the use of survey strategy during navigation. These results seem to suggest that in the learning of a route in real environment, VSWM support the encoding and maintaining of spatial information useful to construct a survey representation from which to infer information even about routes never travelled before. In addition these results supported the view that the construction of a spatial representation involves more variables, cognitive factors and individual differences.

In Experiment 3 we extended the analysis of factors involved in the acquisition of survey knowledge to external factors, investigating whether and how the presence of landmarks influence the process of building up a spatial representation. In line with literature (Foo et al., 2005; Riecke et al., 2002) we showed that landmarks are helpful in finding shortcuts and we added that their help is related to individual differences. In fact we found that they are more helpful for people with low sense of direction: in absence of them, the sense of direction, is the predictor for successful performance.

In the last experiment, Experiment 4, we focused on the role of another external factor, the instructions about the task to perform after navigation. There is some evidence that the instructions act on how people interact and encode spatial information. The few studies analyzed the influence of the instructions (Magliano et al., 1995, Taylor et al., 1999; Brunye et al., 2009; studies with children: Gauvian & Rogoff, 1986) suggested that the instructions guide navigation behaviour leading to different spatial representation but the processes involved are not clear. In Experiment 4 we explored the role of route and survey instructions in the acquisition of spatial knowledge in relation to the involvement of working memory. Our results showed that the interference effect of spatial dual task in the acquisition of spatial knowledge is less if participants receive survey instruction in respect to participants with route instructions. These results suggested that instruction not only improve the acquisition of specific spatial knowledge but they can influence even the involvement of cognitive resources.

Summarizing, the main questions of this dissertation were: do we need the same type of memory to retrace a route and finding shortcut? Which factors are involved in the construction of route and survey representation? This project supported that the ability to retrace a route depends on encoding and maintaining the information in VWM and VSW whereas the ability to find a shortcut seems to be related on the involvement of VSWM. In addition our results confirmed that there are large individual differences in both the ability to learn spatial layout and in how spatial layout is preferentially encoded, and added that the sense of direction becomes the predictor of the acquisition of survey knowledge in the learning condition without landmarks. Moreover our results showed that in the process of acquisition of spatial knowledge, external factors are also implicated, showing that the presence of landmarks and receiving specific instructions about the task, help the construction of mental representation. In conclusion our results mature the growing body of literature supporting that the acquisition of spatial knowledge is a multi-level process influenced by internal and external factors.

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Appendix

Questionnaire on spatial representation (QOS, Pazzaglia, Cornoldi, & De Beni, 2000)

1. Do you think you have a good sense of direction?

2. Are you considered by your family or friends to have a good sense of direction?

3. Think about the way you orient yourself in different environments around you. Would you describe yourself as a person:

a. who orients him/herself by remembering routes connecting one place to another.

b. who orients him/herself by looking for well-known landmarks.

c. who tries to create a mental map of the environment

4. Think of an unfamiliar city. Write the name……Now try to classify your representation of the city:

a. survey representation, that is a map-like representation

b. route representation, based on memorizing routes

c. landmark-centered representation, based on memorizing single salient landmarks (such as monuments, buildings, crossroads, etc.)

5. When you are in a natural, open environment (mountains, seaside, country) do you naturally individuate cardinal points, that is where north, south, east and west are?

6. When you are in your city do you naturally individuate cardinal points, that is do you find easily where north, south, east and west are?

7. Someone is describing for you the route to reach an unfamiliar place. Do you prefer:

a. to make an image of the route

b. to remember the description verbally

8. In a complex building (store, museum) do you think spontaneously and easily about your direction in relation to the general structure of the building and the external environment?

9. When you are inside a building can you easily visualize what there is outside the building in the direction you are looking?

10. When you are in an open space and you are required to indicate a compass direction (north-south-east-west), can you point immediately?

11. You are in a complex building (many floors, stairs, corridors) and you have to indicate where the entrance is, can you (circle one) indicate immediately it?

Spatial Anxiety Scale (Lawton, 1994)

1. Leaving a store that you have been to for the first time and deciding which way to turn to get a destination.
2. Finding your way out a complex arrangement of offices that you have visited for the first time.
3. Pointing in the direction of a place outside that someone wants to get to and has asked you for directions, when you are in windowless room.
4. Locating your car in a very large parking lot or parking garage.
5. Trying a new route that you think will be a shortcut without the benefit of a map.
6. Finding your way back to a familiar area after realizing you have made a wrong turn and become lost while driving,
7. Finding your way around in an unfamiliar mall.
8. Finding your way to an appointment in an area of a city or town with which you are not familiar.

Auto-efficacy Scale (adapted by Lawton, 1994)

1. Leaving a store that you have been to for the first time and deciding which way to turn to get a destination.
2. Finding your way out a complex arrangement of offices that you have visited for the first time.
3. Pointing in the direction of a place outside that someone wants to get to and has asked you for directions, when you are in windowless room.
4. Locating your car in a very large parking lot or parking garage.
5. Trying a new route that you think will be a shortcut without the benefit of a map.
6. Finding your way back to a familiar area after realizing you have made a wrong turn and become lost while driving,
7. Finding your way around in an unfamiliar mall.
8. Finding your way to an appointment in an area of a city or town with which you are not familiar.

Object-Spatial Imagers Questionnaire (OSIQ, Blajenkova, Kozhevnikov & Motes, 2005)

1. I was very good in 3-D geometry as a student.
2. If I were asked to choose between engineering professions and visual arts, I would prefer engineering.
3. Architecture interests me more than painting.
4. My images are very colourful and bright.
5. I prefer schematic diagrams and sketches when reading a textbook instead of colourful and pictorial illustrations.
6. My images are more like schematic representations of things and events rather than detailed pictures.
7. When reading fiction, I usually form a clear and detailed mental picture of a scene or room that has been described.
8. I have a photographic memory.
9. I can easily imagine and mentally rotate 3-dimensional geometric figures.
10. When entering a familiar store to get a specific item, I can easily picture the exact location of the target item, the shelf it stands on, how it is arranged and the surrounding articles.
11. I normally do not experience many spontaneous vivid images; I use my mental imagery mostly when attempting to solve some problems like the ones in mathematics.
12. My images are very vivid and photographic.
13. I can easily sketch a blueprint for a building that I am familiar with.
14. I am a good Tetris player.
15. If I were asked to choose between studying architecture and visual arts, I would choose visual arts.
16. My mental images of different objects very much resemble the size, shape and colour of actual objects that I have seen.
17. When I imagine the face of a friend, I have a perfectly clear and bright image.
18. I have excellent abilities in technical graphics.
19. I can easily remember a great deal of visual details that someone else might never notice. For example, I would just automatically take some things in, like what color is a shirt someone wears or what color are his/her shoes.
20. In high school, I had less difficulty with geometry than with art.

21. I enjoy pictures with bright colors and unusual shapes like the ones in modern art.
22. Sometimes my images are so vivid and persistent that it is difficult to ignore them.
23. When thinking about an abstract concept (e.g. ‘a building’) I imagine an abstract schematic building in my mind or its blueprint rather than a specific concrete building.
24. My images are more schematic than colorful and pictorial.
25. I can close my eyes and easily picture a scene that I have experienced.
26. I remember everything visually. I can recount what people wore to a dinner and I can talk about the way they sat and the way they looked probably in more detail than I could discuss what they said.
27. I find it difficult to imagine how a 3-dimensional geometric figure would exactly look like when rotated.
28. My visual images are in my head all the time. They are just right there.
29. My graphic abilities would make a career in architecture relatively easy for me.
30. When I hear a radio announcer or a DJ I’ve never actually seen, I usually find myself picturing what he or she might look like.

Santa Barbara Sense-of-Direction Scale (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002)

1. I am very good at giving direction
2. I have a poor memory for where I left things
3. I am very good at judging distances
4. My sense of direction is very good
5. I tend to think at my environment in terms of cardinal direction
6. I very easily get lost in a new city
7. I enjoy reading maps
8. I have trouble understanding directions
9. I am very good at reading maps
10. I don’t remember routes very well while riding as a passenger in a car
11. I don’t enjoy giving a directions
12. It’s not important to me to know where I am
13. I usually let someone else do the navigational planning for long trips
14. I can usually remember a new route after I have traveled it only once
15. I don’t have very good mental map of my environment

Questionnaire on attitude towards orientation tasks (Pazzaglia, Poli, & De Beni, 2004)

1. I love to explore different places that do not yet know well to find new ways and different place
2. Turn alone in an unfamiliar place gives me a sense of insecurity.
3. When I travel I like to help the driver indicating the direction and consulting the map.
4. Before leaving for a trip and / or vacation I like to find out where on the map are the places I visit.
5. If I go for the first time in a place (such as the house of a friend of mine), accompanied by others, then I know that I could go back to alone.
6. In the company of friends, I often have to point out the best route to go.
7. I think the sense of direction is a skill that is acquired through practice
8. When I go by train or car from one city to another can spontaneously imagine the position of the destination city compared to the original one as if you saw a map.
9. I think some people are born with an instinctive sense of direction.
10. I would like to play a sport as orienteering where people have to move very fast in unknown places.

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