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ENVIRONMENT LEARNING AND NAVIGATION: WHEN GENDER, SPATIAL ABILITIES AND BELIEFS MATTER

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INTRODUCTION

Space and spatial information are fundamental parts of people's daily behaviors and cognition because we live in and are continuously surrounded by space (Ishikawa & Zhou, 2020). In particular, the ability to acquire spatial information from surrounding environments, also called environment learning (Hegarty et al., 2006), plays a fundamental role in people's functioning, as the basis of everyday navigation. It is well-known that people differ broadly in their abilities to learn an environment and navigate in it (Wolbers & Hegarty, 2010), varying along a continuum from expert ability to severe impairment (Iaria & Barton, 2010). Interest is increasing in the individual factors that can sustain and promote environment learning and subsequent spatial recall performance in real and virtual environment. Studies on individual differences have identified gender, visuospatial abilities, and self-reported measures of spatial abilities among people's individual factors to relate to spatial recall performance after learning an environment (Hegarty et al., 2006; Meneghetti et al., 2014; Nazareth et al., 2019). However, despite their importance, self-reported measures of spatial abilities (e.g., spatial self-efficacy, growth mindset, stereotypes) have scarcely been studied empirically. Initial evidence has now shown that with self-reported assessments, motivational and psychosocial factors related to spatial knowledge, also called beliefs about spatial abilities, can play a role in explaining environment learning and spatial recall performance (Allison et al., 2017; Pazzaglia et al., 2017). In addition, within the theoretical framework of Bandura's (1997) self-efficacy theory, Dweck's (2000) incremental theory of mind (or growth mindset), and stereotypes (Steele, 1997), although extensively investigated in other fields (such as academic achievement), these beliefs have only recently been considered in the field of environment learning and navigation behaviors.

Given these premises, this dissertation aimed to investigate the relationships between beliefs about spatial abilities (i.e., spatial self-efficacy, growth mindset, and gender stereotypes), visuospatial abilities, navigation ability (i.e., spatial recall performance after learning a virtual environment), and behaviors (e.g., GPS use). Moreover, another focus was to explore gender differences in beliefs about spatial abilities because such differences may affect environment learning and navigation behaviors, especially in women. The importance of the study of individual factors (i.e., gender, visuospatial abilities, and beliefs about spatial abilities) on spatial recall performance lies in the fact that it might provide theoretical insights about the processes involved in environment learning and the acquisition of spatial knowledge.

Therefore, Chapter 1 presents the theoretical background adopted to define environment learning and its spatial recall tasks. Moreover, it describes individual factors that can influence environment learning and its recall, such as gender, visuospatial abilities, beliefs about spatial abilities (i.e., spatial self-efficacy, growth mindset, and gender stereotypes) and navigation behaviors (i.e., exploration tendency and GPS use). Each of the following chapters (Chapters 2–5) presents one of four studies. Study 1 examined the relationships between gender, spatial self-efficacy, visuospatial abilities, and spatial recall performance in young adults after learning a virtual environment. Study 2 examined whether an experimental manipulation of spatial self-efficacy could improve people's subsequent spatial recall performance after learning a virtual environment. Study 3 examined the relationships between beliefs about spatial abilities (i.e., spatial self-efficacy, growth mindset, and gender stereotypes) and navigation behaviors in men and women. Moreover, it investigated gender differences in beliefs about spatial ability and navigation behaviors (i.e., exploration tendency and GPS use). Study 4 further investigated gender differences in people's spatial recall performance after learning a virtual environment and beliefs about spatial abilities and the relationship between the latter and different types of spatial knowledge. Finally, Chapter 6 includes a general overview of the relevant findings and conclusions made in light of all studies. The Ethical Committee for Psychological Research at the University of Padova and Leiden University approved all of these studies.

CHAPTER 1

Acquiring Spatial Knowledge from Navigation: Individual and Gender Differences

1.1 Environment Learning and Spatial Knowledge: Theoretical framework

Environment learning plays a fundamental role in people's everyday life functioning, as the basis of everyday navigation and daily activities (for example, navigating to a new city or to an unfamiliar airport). When navigating within an environment, a person simultaneously learns spatial information, such as landmarks, distances between landmarks and directions, and the path networks of the environment (see Montello, 2001; Montello & Raubal, 2013). The process of learning spatial information leads to the formation of a cognitive map (Tolman, 1948). Tolman introduced the term "cognitive map" in 1948 while studying rats and proposed the mental construction of a map of the environment after noticing that animals in a maze were able to find novel routes to reach food. Subsequently, the concept of a cognitive map was conceived as a flexible mental representation of the environment (e.g., not associated with a specific orientation; Wolbers & Hegarty, 2010), implying that an individual needs to integrate all the learned information from a single location to comprehend the layout of an environment and create a cognitive map (Ishikawa, 2021).

Various theoretical frameworks have been proposed to understand the ability to acquire information from the environment and create a mental representation of it. One of the most influential works in the literature was that of Siegel and While (1975). The authors postulated that learning a new environment moves through hierarchical stages from landmark knowledge to route knowledge to survey knowledge. First, individuals learn landmarks, such as noticeable characteristics of the environment without location or direction information. After learning landmarks, people learn routes, such as networks of landmarks linked by travel connections and sequences of movements. In the final stage, individuals learn two-dimensional layouts of landmarks and routes, such as the relationships between them, as part of a metric spatial configuration or survey knowledge. This hierarchical structure of knowledge acquisition suggests that people can form survey knowledge (create a mental representation of an environment) only after acquiring landmark and route knowledge accurately.

Later research showed that even after a brief exposure to a new environment, individuals can construct a survey-like representation of it (e.g., Klatzky et al., 1990). These results suggested that the rigid progression previously proposed is not necessary for acquiring spatial knowledge (Ishikawa & Montello, 2006). Accordingly, in 1998, Montello proposed an alternative theoretical model, suggesting that people obtain the three types of knowledge (landmark, route, and survey) from the first moment of exposure to an environment. In fact, being able to return to the starting point or give someone directions after navigating in a new city for only a short time is also a common experience. For this reason, people are more likely to learn spatial knowledge simultaneously and continuously (Montello, 1998). Additionally, Montello suggested that individuals vary substantially in the accuracy and extent of the spatial knowledge they can acquire.

In addition, a key element in environment learning and spatial knowledge is the notion of egocentric (observer-based) and allocentric (environment-based) perspective taking. For example, a location can be coded as being either “to my left” (egocentric) or “west of the train station” (allocentric). Similarly, knowledge of paths and routes can either concern information from a specific route taken (route knowledge) or can be based on a mental representation of an environment from a bird’s eye perspective (survey knowledge; Kozhevnikov et al., 2006; van der Ham & Claessen, 2020). Taken together, the above-mentioned theories highlighted that people can form various types of spatial knowledge and representations.

Hegarty et al. (2006; see also Wolbers & Hegarty, 2010) have subsequently studied the mental representation of the environment considering input processes and outcome measures. They proposed an important model which examined perceptional and cognitive processes related to the ability to represent an environment. The model clarifies that people can acquire information from different sensory inputs and sources such as maps, direct experience, or videos. This leads to an internal representation of the environment that can be tested with various outcome measures. Mental spatial representation can be measured indirectly through spatial recall performance such as remembering the landmarks one encountered, locating a landmark on a map, retracing a previously learned route, estimating directions, or drawing a map of the environment after learning a route (Hegarty et al., 2006). Therefore, the route and survey can refer to either a learning perspective or the type of knowledge that can be tested with various tasks.

Given the complexity and variety of the processes involved, people can differ widely in their performance of such spatial tasks, suggesting a wide variability in navigational abilities also called individual differences (Montello, 1998; Wolbers & Hegarty, 2010). It is well-known indeed that some people have a better sense of orientation or can visualize complex spatial relationships than others. According to Montello's (1998) continuous framework, each person varies in the accuracy of the spatial knowledge that they acquire from direct experience. But what are the essential differences in spatial representations and processes between people with higher and lower spatial abilities and knowledge? Individual factors such as cognitive abilities (e.g., visuo-spatial abilities), motivational and personality factors (e.g., spatial self-efficacy) can intervene differently on how people learn and subsequent recall an environment. Studying individual differences and gender in spatial performance, can provide a comprehensive understanding of environment learning and spatial knowledge. In the following section, we explore individual factors related to cognitive processes and beliefs about spatial abilities.

1.2 How Individual Factors Relate to Environment Learning and Spatial Knowledge

1.2.1 Gender

Historically, studies investigating the effects of gender differences on psychological processes have existed since the beginning of psychological research. In fact, in the past, a lot of psychology books have investigated and delved into the role of gender and considered it one of the most important individual factors for understanding behavior and cognition (Halpern, 2012; Richardson, 1997).

Additionally, in the spatial cognition domain, gender was one of the first individual factors studied for about 35 years (Halpern, 2012). The earliest studies of gender differences in spatial cognition focused on visuospatial abilities showing that men perform better than women in mental rotation abilities and spatial perceptions (e.g., Linn & Petersen, 1985; Voyer et al., 1995). Later, extensive literature confirmed men's better performance with mental rotation abilities across the life span (Geiser et al., 2008; Moè, 2018; Voyer et al., 1995) to the point that gender differences in mental rotation are considered among the most stable of the cognitive abilities (Halpern, 2012).

More recently, researchers have become interested in gender differences in more large-scale navigation abilities and have conducted some reviews and meta-analyses on gender differences in environment learning and navigation. For example, Nazareth et al. (2019) analyzed a variety of studies that covered different populations, methodologies, and tasks such as pointing, retracing learned routes, orienting themselves with cardinal directions, positioning via landmarks, or navigating with verbal instructions. Their results showed that, overall, men outperformed women, with a small to medium effect size (d = 0.34–0.38). Similarly, another systematic review found that men had advantages in both navigation (large-scale abilities) and visuospatial abilities (small-scale abilities; see Section 1.2.3; Yuan et al., 2019). However, gender differences are less marked when other factors—such as type of task, type of environment, perspective used (survey vs. route), and time pressure—are taken into account as moderators (Nazareth et al., 2019; Yuan et al., 2019).

Despite the overall general effect size in favor of men, importantly, the results between studies have been mixed and may have depended on the type of spatial knowledge studied and the specific task used to measure navigation or spatial knowledge (for a review, see Coluccia & Louse, 2004).

Regarding the type of spatial knowledge (e.g., route or survey), men seem to perform better than women on tasks that require survey knowledge (Coluccia & Louse, 2004). For instance, men have been found to be more accurate than women when locating landmarks on a map (e.g., Burles & Iaria, 2020; Castelli et al., 2008; Tlauka et al., 2005), pointing to an unseen location (e.g., Fields & Shelton, 2006; Ishikawa & Montello, 2006), navigating using cardinal directions (e.g., Saucier et al., 2002), or taking shortcuts (Boone et al., 2018). Nonetheless, when the environment used in the survey task was presented and learned from a map, there were also cases in which women performed better than men or no gender difference emerged (Coluccia & Louse, 2004). In contrast, when researchers proposed tasks that required route knowledge, the differences between men and women were less clear: Some studies found that men had better performance (e.g., Tlauka et al., 2005; van der Ham et al., 2020), whereas no differences emerged in other studies (Castelli et al., 2008; Choi et al., 2006; Saucier et al., 2002). Underlying such gender differences in spatial knowledge and environment learning could be differences in how men and women encode spatial information during navigation. Some studies have suggested that women prefer to encode landmark information from an egocentric first-person perspective, whereas men focus more on the configural global information of an environment (Coluccia & Louse, 2004; Saucier et al., 2002). Women's preferences for using egocentric and landmark-based information to orient themselves and learn environments could also be related to their better performance in object–location memory tasks compared to men (for a meta-analysis, see Voyer et al., 2007; West et al., 2007).

A few studies have investigated whether other variables can mediate the relationship between gender and environment learning, such as wayfinding behaviors (e.g., pausing or revisiting) or visuospatial abilities. For example, Munion et al. (2019) examined whether men and women moved through the environment differently and whether these differences in wayfinding behaviors could explain men's and women's abilities to locate targets in large-scale environments. Their results demonstrated that men use more directional persistence and less revisiting and pausing during navigation compared to women and that these gender differences in wayfinding behaviors accounted for the relationship between gender and navigational performance (Munion et al., 2019). Another study found that the relationship between gender and performance in a route tracing task was mediated by spatial abilities, such as mental rotation ability and visuospatial working memory, but not by emotional–motivational factors or personalities (Pazzaglia et al., 2018). Taken together, these results suggested that both cognitive abilities and the ways men and women navigate (such as navigation behaviors) can be related to performance in navigation ability and environment learning (Munion et al., 2019; Pazzaglia et al., 2018).

Many theories have been offered to explain gender differences; however, the origin of the gender differences described above is still unknown. Evolutionary psychologists have proposed one explanation suggesting that the different behaviors of men and women emerged as part of the hunter–gatherer way of life (hunter–gatherer hypothesis; Burke et al., 2012). Men in prehistoric times were hunters moving in unfamiliar environments by using navigation strategies and coordinates, while women's mobility was reduced and related mainly to foraging activities in the nearby surrounding (Burke et al., 2012). Other explanations (biological) have hypothesized that sex hormones could explain gender differences in spatial abilities: Men's performance seems to depend on variations in testosterone levels, with higher levels being associated with better performance (Coluccia & Louse, 2004; Moffat & Hampson, 1996). Other studies have proposed that the differences in favor of men (especially in survey tasks) are due to the use of different strategies used to solve environment tasks in men and women. As mentioned above, men use allocentric strategies more frequently whereas women prefer egocentric or route-based strategies. The difference in the use of strategies was confirmed both by asking participants about their preferences with self-report measures and empirically while performing navigation tasks (Boone et al., 2018; Lawton, 2010; Padilla et al., 2017). Other studies have advanced the hypothesis that differences between men and women in navigation and environment learning could be related to differences in visuospatial working memory spans (Coluccia & Louse, 2004). This explanation could be related to the results of a meta-analysis on gender differences in visuospatial working memory showing that men have a small advantage (Voyer et al., 2017). However, given the small effect size found, studies clarifying that gender differences in visuospatial working memory (VSWM) might partially account for the gender differences in environment learning or navigation.

Finally, experiences during childhood and adolescence (opportunities to drive, travel, and commute) can play a role in enhancing gender differences in navigation performance (Beanninger & Newcombe, 1989; Lawton, 2010).

Given the complexity of environment learning, spatial knowledge, and the various methods and tasks used to examine gender differences, is difficult to obtain a single conclusion from the literature on gender differences in environment learning and navigation ability. Studies on gender differences and the explanations for it have focused especially on cognitive aspects and accounted for some of those reasons. We believe that forming a comprehensive view of individual differences considering cognitive and self-reported measures is necessary.

1.2.2 Navigation Behaviors

Other important factors related to environment learning and spatial knowledge are navigation behaviors, or the way people navigate within environments. During navigation and environment learning, people may enact behaviors very differently from each other. For example, people tend to explore the environment during navigation on one hand or to rely on navigation technologies with GPS on the other (He & Hegarty, 2020). Research on navigation behaviors showed that people who explored more in a new environment created more accurate knowledge of the environment (as measured by a pointing task) than those who explored the environment less (Gagnon et al., 2018). Correlational studies found that the self-reported exploration tendency (also called pleasure in exploring) is positively related to performance in a variety of tasks, such as drawing a map (Muffato et al., 2020), pointing towards a landmark using cardinal directions (Meneghetti et al., 2014), or finding shortcuts in an unfamiliar environment (Pazzaglia et al., 2017, 2018).

Concerning GPS use, in recent years, devices and aids have become very important instruments for orienting people and helping them reach their destinations successfully. However, when testing the mental representations of people who use GPS devices, physical maps, or exploration, researchers found that GPS users seemed to perform less accurately than people who directly navigated the environment or used physical maps (Ishikawa, 2019; Ishikawa et al., 2008). An explanation of these results might depend on the fact that navigation with GPS is a more passive task than navigation without aids (Ben-Elia, 2021) and that during navigation, one's attention is divided between the environment and the device (Gardony et al., 2013). Additionally, Dahmani and Bohbot (2020) discovered (using a longitudinal approach) that the usage of GPS was connected to a deterioration in spatial memory. These results seem to highlight a negative effect of the long-term GPS use (Dahmani & Bohbot, 2020; Ruginski et al., 2019); nevertheless, Nori et al. (2022) found that, using GPS may have a positive effect on one's sense of direction at first. More evidence needs to be gathered to understand how and to what extent navigation behaviors influence people's navigation.

1.2.3 Visuospatial Abilities

A definition commonly used in spatial cognition focuses on the capacity to acquire spatial knowledge by distinguishing between small- and large-scale spatial abilities. Small-scale spatial abilities, also called visuospatial cognitive abilities, consist of high-order cognitive abilities defined as the ability to generate, retain, and process abstract visual images (Lohman, 1988). Linn and Petersen (1985) provided one of the earliest classifications of visuospatial abilities and included three factors: spatial perception (ability to determine spatial relationships with respect to one's own position), spatial visualization (ability to perform manipulations of complex spatial information), and mental rotation (ability to mentally rotate figures). Mental rotation ability has been distinguished as object based because it requires identifying a 3D object in rotated positions and perspective based because it requires the individual to imagine adopting new perspective on a configuration of objects (Hegarty & Waller, 2004).

Various studies on spatial cognition have also included visuospatial working memory (VSWM), the ability to retain and process visuospatial information (Baddeley, 2000), in the classification of visuospatial abilities. Although VSWM and mental rotation abilities are different constructs and processes, they are highly related (Hegarty et al., 2006); therefore, researchers have considered them both as separate factors (e.g., Muffato et al., 2020) and as a single factor (e.g., Pazzaglia et al., 2018).

Overall, it has been well established that visuospatial abilities contribute to maintaining environment learning and gaining spatial knowledge, even though they entail some distinctions depending on the type of information learned (map or video; Fields & Shelton, 2006; Hegarty et al., 2006; Meneghetti et al., 2014, 2021).

One of the early studies on the relationship between visuospatial abilities and environment learning considered visuospatial abilities in a unitary model, such as by overlapping and reflecting the same cognitive skills (e.g., Gärlin & Golledge, 1989); afterward, however, a key article by Hegarty et al. (2006) demonstrated a partial dissociation model in which were partially disconnected, suggesting environment learning and visuospatial abilities had only some cognitive processes in common.

1.2.4 Self-Reported Spatial Factors: Beliefs About Environment Learning and Spatial Knowledge

Another source of variability in environment learning consists of individual beliefs about spatial abilities, also called wayfinding inclinations (Meneghetti et al., 2021). Compared to visuospatial abilities and cognitive performances, the role of beliefs about spatial abilities has been investigated less in the literature on spatial cognition. In addition to the actual performance of men and women, researchers may need to understand the subjective experiences of men and women and the explicit thoughts that may influence their navigation behavior and performance. Studying these aspects could possibly help to create a better understanding of the complex theoretical framework behind environment learning and navigation ability. Among beliefs about spatial ability, less research has been done on motivational (i.e., self-efficacy or growth mindset) and psychosocial factors (i.e., gender stereotypes).

1.2.4.1 Spatial Self-Efficacy

Bandura (1977) introduced the construct of self-efficacy and was the first to define and utilize this term. Self-efficacy is defined as people's beliefs about their capabilities to produce levels of performance (Bandura, 1994) or as personal judgments about one's ability to accomplish a task (Bandura, 1977). Importantly, self-efficacy is not a general assessment of ability but is tied to a specific domain. Self-efficacy consists in judging one's personal capabilities to perform a given task not the ways people feel about themselves in general. Similarly, other authors have considered self-efficacy a set of beliefs organized hierarchically, from global beliefs about a certain ability (e.g., "I have a good memory") to task-specific and concurrent beliefs (e.g., "I can remember this phone number"; Herzog & Dixon, 1994). The prediction of one's ability to accomplish a task (concurrent beliefs) takes into account the influence of factors related to the context in which the task has to be performed (Bandura, 1989; Beaudoin & Desrichard, 2011). Therefore, self-efficacy is not a static construct but is dynamic and subject to changes in task demands, individual characteristics, and situational factors (Berry & West, 1993).

Personal self-efficacy is also related to people's emotions, beliefs, behaviors, and cognitive functioning (Bandura, 1993). Self-efficacy can influence people's cognitive performance in several ways; for example, self-efficacy is related to the task strategies adopted, the levels of effort and persistence maintained, or the affect (e.g., anxiety) experienced in a performance situation (Bandura, 1989). Moreover, a higher sense of efficacy can affect the ways people set challenging goals, approach difficult tasks as challenges, and maintain effort through failures (Bandura, 1994). Therefore, people with the same levels of ability but different levels of self-efficacy may approach and subsequently perform a task very differently (Bandura, 1977).

According to Bandura's (1977) self-efficacy theory, self-efficacy can be developed through four main sources of influence, such as experiences, which serve as sources of information for one's perception of efficacy: (a) verbal persuasion, (b) mastery experience, (c) vicarious experience, and (d) arousal. Verbal persuasion consists of evaluations or judgments given to the person who will act in order to reinforce the belief that the person has the skills necessary to perform a task. A person is more likely to maintain their sense of self-efficacy if other people express confidence in the abilities of that person. Therefore, if evaluations are positive and realistic, verbal persuasion can serve to sustain performance (Bandura, 1977). Persuasive information can be conveyed through feedback.

Bandura introduced the concept of feedback that emphasizes a person's abilities and commitment to the task, while other researchers have studied feedback based on social comparison. A typology of feedback consisting of giving information on one's performance compared to the performance of others (e.g., an above-average performance) is called *normative feedback*. Studies that have implemented normative feedback and explored its effect on cognitive performance administered various kinds of tasks, for example, arithmetic tasks, name recall, or motor skills learning. The results showed that in the different tasks, normative feedback seemed to facilitate performance (e.g., Strickland-Hughes et al., 2017; Wulf et al., 2010), suggesting that fictitious positive normative feedback could be an effective intervention to promote self-efficacy and cognitive or motor performance (Peifer et al., 2020). However, to our knowledge, no studies have used normative feedback specifically in the spatial cognition domain, but only regular feedback. For instance, in a study by Ishikawa and Zhou (2020), during a 6-week training session, one group received feedback on its performance after some spatial learning tasks (distance estimation, direction estimation, and sketch maps), whereas another group did not. Repeated trials with feedback were effective for improving accuracy in straight-line distance estimates and sketch maps.

Among the four sources of self-efficacy, the most effective seems to be mastery experience, such as the expertise one gains through direct experience. In mastery experience, successes foster self-efficacy, whereas failures undermine it. In other words, people's experiences and interpretations of that can influence their subsequent beliefs about self-efficacy, and previous experiences serve as additional feedback for people (Bandura, 1994).

The self-efficacy theory has also been applied to spatial ability; indeed, the term "spatial self-efficacy" must encompass the personal beliefs about one's ability to accomplish an environmental and navigational task (Mitolo et al., 2015; Pazzaglia et al., 2017, 2018). Very few studies have investigated spatial self-efficacy. They have measured spatial self-efficacy using questionnaires (e.g., Wayfinding Self-Efficacy Questionnaire or Spatial Self-Efficacy Questionnaire) in which people judged their self-efficacy in general environmental situations (e.g., "Finding your car in a large parking lot"). The results have shown that spatial self-efficacy is related to the ability to find a shortcut in a virtual environment, especially one that is more complex. Specifically, participants with higher levels of self-efficacy correctly found the shortest path to reach a destination, especially in virtual environments without landmarks (Pazzaglia et al., 2017, 2018). However, whether spatial self-efficacy is associated with different types of spatial knowledge (besides the shortcut task) and whether task-specific spatial self-efficacy is also associated with task performance and if it is more predictive of the performance are unclear.

In the context of spatial self-efficacy, a clarification should be made regarding the sense of orientation (SOD) construct. The SOD is a self-report measure generally defined as a person's self-reported estimate of their ability to orient themselves and navigate (Kozlowski & Bryant, 1977). Notably, SOD might be a related measure resembling spatial self-efficacy in part. Asking a person to evaluate their sense of direction implies that the person will think about the way they perceive being able to approach navigation and orientation in their environment. This affinity between the two constructs has also been proven with the high Pearson's correlations between SOD and self-efficacy ($r = .56$; $r = .57$) that have emerged in previous studies (Pazzaglia & Meneghetti, 2017).

Concerning gender, so far, few studies have paid attention to gender differences in spatial self-efficacy. West et al. (2002) showed that despite women performing well with object locations, women reported lower self-efficacy than men in remembering the locations of objects, routes in buildings or cities, and spatial arrangements of rooms. To date (and to our knowledge), no study has investigated the relationships between gender, spatial self-efficacy (or its sources), and environment learning.

1.2.4.2 Growth Mindset in Navigation Ability

Among the beliefs about environment learning and spatial knowledge is the *growth mindset*. The growth mindset is defined as a set of beliefs that a person can improve and enhance an ability or performance. A growth mindset is opposed to a fixed mindset, in which a person believes an ability is not malleable and cannot be improved (Dweck, 2006). In other words, a person can view an ability as malleable (incremental) or gifted (fixed).

Dweck and Bandura first studied the concepts of ability in relation to the general construct of intelligence, calling them implicit theories of intelligence. They chose this name because the ideas about what intelligence is and how it works are potentially falsifiable and people usually are unaware of them. The two implicit theories were originally called entity and incremental theories, but these names later were changed to "fixed mindset" and "growth mindset," respectively (Dweck, 2006; Dweck & Yeager, 2019).

One of the first areas in which the growth mindset was applied is that of academic achievement, and numerous studies have found that students perform better if they believe their intellectual abilities can be developed than if they believe their intellectual abilities are immutable and people are born with certain abilities (Dweck, 2000). Studies on academic achievement have proposed numerous ways in which mindsets influence behaviors and student achievement (Mueller & Dweck, 1998). For example, students who adopt a growth mindset tend to persist through failure and set more adaptive goals than those who believe in a more fixed nature of ability (Elliot & Dweck, 2013). On the contrary, students with fixed mindsets tend to avoid situations in which they might struggle or fail. As a consequence, students who have growth mindsets tend to earn better grades than students who hold fixed mindsets (Blackwell et al., 2007).

Although the studies on the growth mindset originated within an academic context, they have extended the theory to other domains, such as athletics (e.g., Kasimatis et al., 1996; Ommundsen, 2003), leadership (Burnette et al., 2010), management, and parenting (Dweck, 2006).

Concerning the spatial cognition domain specifically, various studies have investigated the concept of the malleability of spatial skills and attempted to improve spatial skills through cognitive training (e.g., Meneghetti et al., 2016; Mitolo et al., 2017). A meta-analysis by Uttal et al. (2013) concluded that trainings in spatial abilities were effective and the effects were transferrable (Ishikawa & Zouh, 2020). Besides cognitive training, only one study—to the best of our knowledge—has measured what people think about the malleability of their personal navigation abilities, such as their growth mindsets on navigation abilities. He and Hegarty (2020) assessed the growth mindset regarding navigation abilities and general intelligence. Their results showed that people have more fixed mindsets about their navigation abilities than about their general intelligence. In other words, participants were less likely to believe that their navigation abilities could be improved than that their intelligence could be improved. The authors then hypothesized that people with growth mindsets would enact different navigation behaviors to overcome spatial challenges. They expected the growth mindset to be associated with the tendency to explore the environment that facilitates the acquisition of knowledge about the environment. On the contrary, they expected a more fixed mindset to be associated with GPS use. The results showed that the growth mindset was weakly associated with the navigation behavior of the tendency to explore and with GPS use, suggesting other factors might intervene in this relationship. In addition, no studies, to our knowledge, have investigated the relationship between the growth mindset and objective tasks of environment learning and subsequent recall.

1.2.4.3 Gender Stereotypes

Gender stereotypes consist of beliefs about the behaviors or characteristics of each sex (Del Boca & Ashmore, 1980). Gender stereotypes are indifferently shared by women and men, and their implications can affect stereotype users and targets among both genders (Ellemers, 2018). More specifically, a gender stereotype exists when people believe that men or women show better performance in a certain ability. In general, these beliefs could make the presumably less capable group fear they will confirm the negative stereotype and lead to underperformance. In contrast, the same belief could lead to improved performance among those expected to be more capable. The two experiences described above are called *stereotype threat* and *stereotype lift*, respectively (Spencer et al., 1999; Steele, 1997; Walton & Cohen, 2003). Researchers interested in stereotypes have usually adopted experimental paradigms including explicit stereotype threat manipulation (Spencer et al., 1999) and a control condition in which the negative stereotype is nullified. Specifically, there are two conditions: the stereotype threat condition, in which a task is either described as diagnostic between two groups or explicitly expected to show a specific performance between the two groups; and the no stereotype threat condition, in which the task is presented as nonevaluative and no performance information is given.

Different processes have been proposed as underlying the stereotype threat effect. Studies have suggested that people under a stereotype threat condition may experience anxiety and interfering thoughts that can undermine their performance (Spencer et al., 1999). Another explanation is that under a stereotype threat, a person's cognitive resources are lower because they are divided between the task and the worry about confirming the stereotype (Steele & Aronson, 1995).

Until now, most studies on gender stereotypes and spatial abilities have focused on visuospatial abilities (small-scale), especially mental rotation ability, showing that both positive and negative stereotype instructions can either favor or harm one's performance in mental rotation ability (e.g., Guizzo et al., 2019; Moè, 2012, 2018). Despite some effects seen in single studies, one meta-analysis tried to summarize the effects of stereotype activation in the context of gender differences in spatial tasks (especially in mental rotation tasks; Doyle & Voyer, 2016); showing no consistent effect of stereotype threat in either men or women.

Only a few studies have considered gender stereotypes and large-scale abilities (such as navigation or environment learning), the initial evidence has suggested men and women agreed that men are better at remembering places and directions (Crawford et al., 1989). More recent studies have investigated gender stereotypes by giving participants instructions before performing a task. One study, for example, manipulated the stereotype using instructions indicating that the results of the participants' performance on the spatial task tested would be used to investigate any gender differences and that the performance of participants of one gender would be compared with that of the opposite gender. The results showed that activating the general navigation stereotype improved the performance of men on the navigation task in a virtual environment, compared to the control condition (stereotype lift; Rosenthal et al., 2012). In another study, the manipulation instead consisted of informing participants that they were likely to perform better, worse, or the same as members of the opposite sex on navigation tasks. Experiment 1 showed an effect of stereotype threat in only the men's performance. However, a second experiment found an effect of stereotype threat for both men and women but only on a more difficult task (Allison et al., 2017). Taken together, the existing literature on the beliefs about spatial abilities is not extensive; moreover, no studies have investigated gender stereotype beliefs by measuring it explicitly or investigating the explicit relationship between gender stereotypes and spatial beliefs, such as in spatial self-efficacy, growth mindset, and environment learning.

In light of previous evidence on spatial cognition, this dissertation aimed to fill the gaps mentioned above in the literature on environment learning and spatial knowledge and to determine the role of certain individual spatial factors and gender differences in relation to virtual environment learning. Understanding individual differences in navigation ability can allow researchers to have a better picture of why men and women may differ in certain navigation tasks. Gender, cognitive (e.g., visuospatial abilities) and self-reported factors (e.g., beliefs about spatial abilities) have been studied separately so far, whereas in this dissertation we have jointly investigated these aspects to better understand their relationships and effects on the ability to learn an environment and navigate it. It is worth noting, furthermore that the great diversity in type of spatial knowledge and measures for assessing environment learning and gender differences requires further research on individual differences. Therefore, the first study aimed to investigate the relationships between gender, visuospatial abilities (i.e., mental rotation ability and VSWM), global and task-specific spatial self-efficacy, and spatial recall performance after the participants learned a virtual environment. A second study was then planned to explore the role of positive normative feedback on visuospatial task performance in subsequent spatial recall performance after the participants learned a virtual environment and the role of task-specific spatial self-efficacy in spatial recall performance. Another main point was to investigate whether patterns or relationships between spatial self-efficacy, growth mindset, gender stereotypes, and navigation behavior (i.e., exploration tendency and GPS use) were different for men and women. This was the main aim of the third study. In a 4 study, we considered the spatial knowledge classification proposed by Claessen and van der Ham (2017) to further investigate how beliefs about spatial abilities and gender relate to different performance in spatial recall tasks after the participants learned a virtual environment. In particular, the classification suggests dissociable domains of navigation: i) landmark knowledge, involving the capacity to recall environment-based elements; ii) their locations, using both the observer's based mode (location-egocentric knowledge) and the environment based mode (location-allocentric knowledge); and iii) path-knowledge using both the knowledge of the set of features encountered along the way (path-route knowledge) and the connections between features seen on a map (path-survey knowledge; Taylor & Tversky, 1992). Table 1.1 presents a summary of the studies.

In conclusion, investigating people's ability to learn environments not only in relation to visuospatial abilities, but also in combination with gender and beliefs about spatial abilities, contributes to better understanding of the mechanisms involved in the ability to learn environments and navigation and provides evidence about a fundamental ability for people's autonomy and functioning in daily life.

Table 1.1 *Overview of the content of the four studies*

Aims of the studies	Sample	Materials				Procedure
		Individual visuospatial factors		*Virtual environment learning*		
Study 1: Investigating the relationship between gender, spatial self-efficacy, visuospatial abilities and environment learning	N= 173 (age range: 19-33, [*M* = 21.86 years, *SD* = 2.45]; women: 64%)	Self-reported Wayfinding Self-Efficacy Questionnaire (Mitolo et al., 2015; Pazzaglia et al., 2017) Task-Specific Self-Efficacy single item.	Cognitive task Short Mental Rotations Test (sMRT; De Beni et al., 2014). Jigsaw Puzzle Test (JPT; De Beni et al., 2008).	*Encoding phase* Participant learned a specific route by actively navigating the environment twice	*Testing phase* Pointing task Map-completion task	All participants completed the questionnaires. Then, they learned the virtual environment and performed two spatial recall task. Before each spatial recall task participants evaluated their task-specific self-efficacy
Study 2: Investigating whether self-efficacy manipulated through positive vs neutral feedback after visuospatial tasks (small-scale) can have an effect on performance in navigation in virtual environment and task-specific self-efficacy in spatial navigation	N= 231 (age range: 18-40, [M= 23.85; SD= 4.06], women 48%)	Participants were randomly assigned to: *Positive feedback condition* Feedback about participants performance after the three visuospatial tasks: route task, survey task and map memory tasks. Specifically, for each task, we displayed a high fictitious (but plausible) score and the corresponding indication that the participant's performance was above or significantly above average. *Individual visuospatial factors*		*Neutral condition* For each task, we displayed that the tasks had been completed, without any further information on the performance. *Virtual environment learning*		All participants completed the questionnaires. Then, they were randomly assigned to the neutral or positive feedback conditions. Subsequently, they learned the environment (video) and they performed (a) the

		Self-reported Wayfinding Self-Efficacy Questionnaire (Mitolo et al., 2015; Pazzaglia et al., 2017) Task-Specific Self-Efficacy single item Sense of Direction and Spatial Representation Questionnaire (SDSR; Pazzaglia & Meneghetti, 2017). Spatial Anxiety Scale (SAS; De Beni et al., 2014).	Cognitive task Route task Survey task Map memory	*Encoding phase* Participant learned a specific route by watching a video twice	*Testing phase* Pointing task Map-completion task Route retracing task	route-retracing task, (b) the pointing task, and (c) the map-completion task. Before each spatial recall task participants evaluated their task-specific self-efficacy
Study 3: Investigating the relationship between navigation behaviors and beliefs about spatial abilities. Investigating gender differences in beliefs and navigation behaviours	N= 609 (age range: 18-50, [M= 23.43; SD= 5.32]; women 48%)	*Beliefs about navigation ability* Self-reported Wayfinding Self-Efficacy Questionnaire (Mitolo et al., 2015; Pazzaglia et al., 2017) Sense of Direction and Spatial Representation Questionnaire (SDSR; Pazzaglia & Meneghetti, 2017). Growth Mindset in Navigation Ability (translated by He & Hegarty, 2020) Gender stereotype in navigation ability questionnaire (GSQ; adapted from Moè & Pazzaglia, 2006).		*Orientation behaviours* Self-reported Exploration tendency questionnaire (ETQ; translated from He & Hegarty, 2020). Measure of global positioning system use (GPS use).		All participants completed the questionnaires in random order except for the questionnaire on gender stereotype in navigation abilities (GSQ) that was completed at the end of the survey
Study 4: Investigating how task-specific self-efficacy, interacts with growth mindset, gender stereotype and mastery experience in the relation with spatial navigation. Investigating gender differences in beliefs about spatial abilities and environment learning	N= 150 (age range: 18-50, [27.22; SD= 7.99], women: 65%)	*Beliefs about navigation ability* Self-reported Growth Mindset in Navigation Ability (translated by He & Hegarty, 2020) Gender stereotype in navigation ability questionnaire (GSQ; adapted from Moè & Pazzaglia, 2006). Mastery experience questionnaire (MEQ; ad hoc) Task-specific self-efficacy Task-specific gender stereotype		*Virtual environment learning* *Encoding phase* Participant learned a specific route by watching a video twice *Testing phase*	Landmark task Location allocentric task Location egocentric task Path route task Path survey	All participants completed the questionnaires. Then a video of a route was presented, and they performed the 5 spatial recall task. Before and after each spatial recall task participants evaluated their task-specific self-efficacy and gender stereotypes.

CHAPTER 2

STUDY 1. Environment Learning in a Virtual Environment: Do Gender, Spatial Self-Efficacy, and Visuospatial Abilities Matter?

2.1 Rationale and Aims of the Study[1]

A large and growing body of literature has showed that people vary substantially in their abilities to learn a virtual environment and to form mental representations of it through navigation (Ishikawa & Montello, 2006; Wolbers & Hegarty, 2010). Previous research has identified gender as one of the individual factors related to environment learning and navigation (Newcombe, 2020). During the past 20 years, some literature reviews and meta-analyses have been conducted on gender differences through a variety of spatial recall and navigation tasks. Overall, they showed that men performed better than women on various tasks with a small effect size (e.g., Nazareth et al., 2019). However, beyond the general effect sizes of these meta-analyses, studies have reported mixed findings depending on the type of task, and gender differences in environment learning are still unclear to date (Coluccia & Louse, 2004).

Gender differences in visuospatial abilities (e.g., mental rotation) seem to be more robust than gender differences in environment learning, showing a larger gender difference in favor of men (Newcombe, 2020; Voyer et al., 1995). In addition, according to one meta-analysis, men perform better in visuospatial working memory compared to women, albeit with a smaller effect size than mental rotation (see Voyer et al., 2017).

To date, studies addressing gender differences in spatial abilities have focused mainly on cognitive variables (e.g., Kaufman, 2007; Voyer et al., 2017), whereas little attention has been devoted to individuals' beliefs about spatial abilities.

[1] Study 1 has been described in Miola, Meneghetti, Toffalini & Pazzaglia (2021)

Among the beliefs about spatial abilities, spatial self-efficacy consists of one's ability to accomplish environmental tasks and is positively associated with the ability to find a shortcut in a virtual environment (Pazzaglia et al., 2018), especially a complex one (Pazzaglia et al., 2017). Importantly, the studies mentioned above measured spatial self-efficacy using questionnaires with items that described general spatial situations to which people indicated their degree of efficacy. In other words, the studies measure a global perception of people's usual abilities in environment learning and navigation. It is important to specify, however, that according to Bandura's self-efficacy theory, self-efficacy is considered a construct highly related to the domain and the task demand (Bandura, 2006). In particular, a good measure of self-efficacy asks people to judge their operational abilities in the present moment (e.g., task-specific self-efficacy; Bandura, 2006; Hertzog & Dixon, 1994).

Although some research has been carried out on spatial self-efficacy and spatial recall performance (e.g., Pazzaglia et al., 2018) and on gender differences in spatial self-efficacy, showing that men have higher spatial self-efficacy (e.g., West et al., 2002), no studies have jointly considered global and task-specific measures of self-efficacy in relation to gender, visuospatial abilities, and spatial recall performance after the participants learned a virtual environment.

Study 1 aimed to investigate the relationships between gender, visuospatial abilities (i.e., VSWM and mental rotation ability), spatial self-efficacy, and spatial recall performance after the young adult participants learned a virtual environment. Further, we measured both global spatial self-efficacy (with a questionnaire) and task-specific spatial self-efficacy (assessed before the participants performed a task) to examine the distinct role of global and task-specific spatial self-efficacy measures in explaining environment learning.

Hypotheses

- *Spatial Self-Efficacy and Environment Learning*. In line with initial findings on wayfinding (finding shortcuts), we expected global spatial self-efficacy to relate positively to spatial recall performance after learning a virtual environment (i.e., map-completion task and pointing task; Pazzaglia et al., 2017, 2018). Furthermore, we expected also task-specific spatial self-efficacy to be associated with spatial recall performance after learning a virtual environment.

- *Visuospatial Abilities and Environment Learning*. Given the well-known relationship between visuospatial abilities and environment learning (Hegarty et al., 2006; Meneghetti et al., 2014) we expected a positive association between visuospatial abilities (i.e., mental rotation and visuospatial abilities) and spatial recall performance after the participants learned a virtual environment.
- *Gender, Spatial Self-Efficacy, Visuospatial Abilities, and Environment Learning*. Furthermore, given some preliminary evidence on gender differences in spatial self-efficacy (e.g., West et al., 2002) and the relationship between the latter and environment learning (Pazzaglia et al., 2017, 2018), we expected global and task-specific spatial self-efficacy to mediate gender differences in spatial recall performance after learning a virtual environment. Moreover, given gender differences in visuospatial abilities (Maeda & Yoon, 2013; Voyer et al., 2017) and the well-established relationship between visuospatial abilities and environment learning (Hegarty et al., 2006), we expected visuospatial abilities to mediate gender-related variance when the participants were performing spatial recall tasks.

2.2 Method

2.2.1 Participants

A total of 173 young adults (64% women) from 19 to 33 years of age (*M* = 21.86 years, *SD* = 2.45) took part in the study. All participants were native Italian speakers and volunteered to take part in the study. They were recruited through word of mouth and through social networks. The study was conducted in accordance with the recommendations of the local university's research ethics committee for psychological science (Approval No. 3432). We informed all participants about the aims of the study and collected their written informed consents. Participants took part in the study from November 2019 to March 2020 at the University's laboratories.

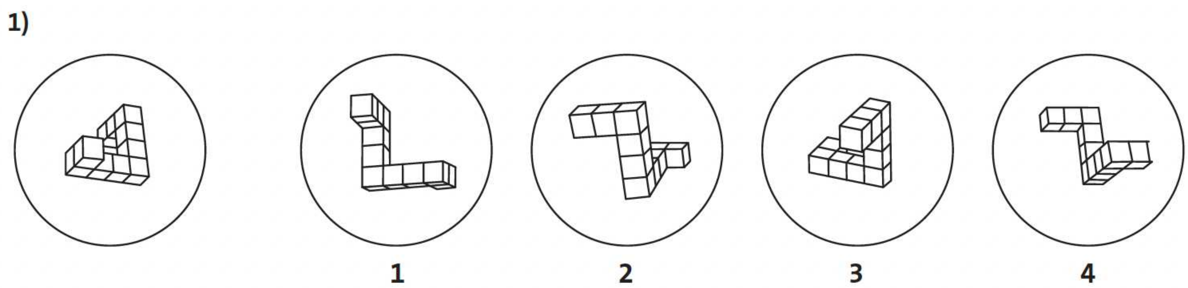
Our sample consisted of at least five observations for each estimated parameter, which is the minimum of participants per parameter used in SEM (Bollen, 1989).

2.2.2 Materials

Visuospatial Cognitive Tasks and Spatial self-assessment measures

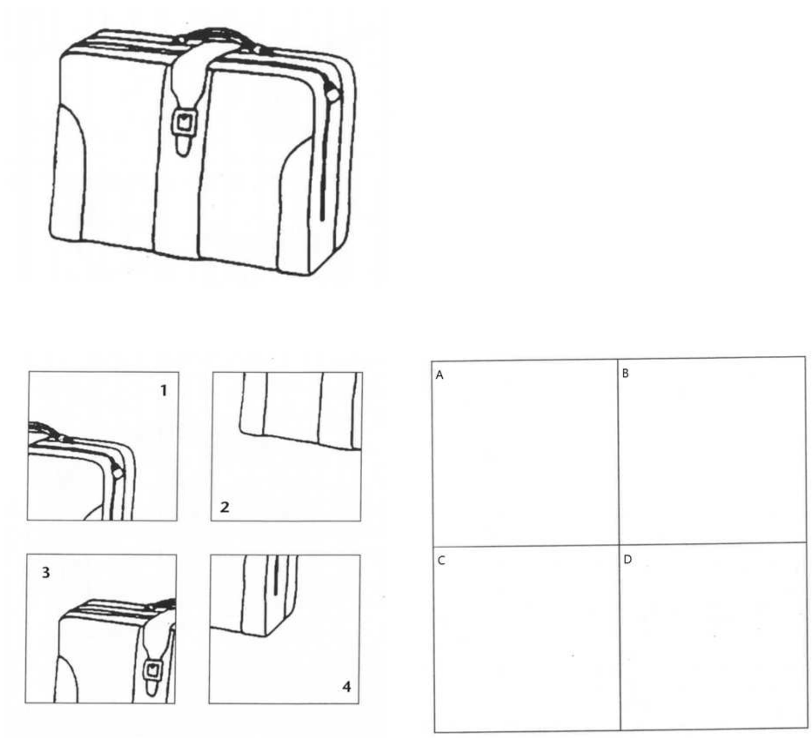
Short Mental Rotations Test (sMRT; De Beni et al., 2014; adapted from Vandenberg & Kuse 1978). The sMRT task consists of 10 items in which participants were required to indicate two of the four figures that were identical to a target one but rotated. All the four figures are 3D assembled cubes in rotated position. The task had to be completed within 5 min. One point was given for the two correctly identified figures in each item. The total score corresponds to the number of correct responces and ranged from 0 to 10. The reliability was acceptable (Cronbach’s alpha coefficient for the current sample: α = 0.79).

Figure 2.1. *Example of item of the mental rotation test.*



Jigsaw Puzzle Test (JPT; Borella et al., 2008). The task contains 27 puzzles with an increasing number of pieces (from 2 to 10). Participants were required to mentally recompose the puzzle without moving the pieces by indicating them in an empty grid. The final score is the sum of the difficulty levels of the last three puzzles solved. The total score ranged from 0 to 29. Test reliability was good (r = 0.83; De Beni et al., 2008).

Figure 2.2. *Example of item of the Jigsaw Puzzle Test.*



Wayfinding Self-Efficacy Questionnaire (Mitolo et al., 2015; Pazzaglia et al., 2017). The questionnaire assesses how individuals feel able to perform environmental tasks and provides a measure of global spatial self-efficacy. It consists of eight items (e.g., “Finding a car in a large parking lot,” “Finding the right path in an unfamiliar environment”) scored on a 6-point scale from (1 = *not at all* to 6 = *very much*). The final score was given by the sum of all the ratings and ranged from 0 to 48. Cronbach’s alpha coefficient for the current sample was 0.81.

Task-Specific Self-Efficacy single item. Before performing each spatial recall task we proposed a single item asking participants to indicate how much they feel able to accomplish the task (i.e., "Now that the task has been explained to you, how well do you feel you can do the task you are about to tackle?"), assigning a score on a 6-point scale (1 = *not at all* to 5 = *very much*).

Virtual Environment and Spatial Recall Tasks

- **Encoding Phase**

The virtual environment used in the present study was modelled with Rhino, Unreal Engine 4.21 at the Department of General Psychology, University of Padova. It consisted of an outdoor environment composed of 19 landmarks (e.g., school, bank, park, a fountain, a monument). Using a joystick, participant covered a specific route (approximately 1 km long) encountering all the landmarks present in the environment. Each participant travelled the path twice by following an avatar during the encoding phase. The image of the video was created at the eye height of 160 cm, and the camera was set with a horizontal field of view of 90°. Rotation and translation settings were fixed for all participants. The walking speed was 4 m/s. The computer (MSI GT63 Titan 8RF-011IT Intel Core i7-8750H - RAM 16GB DDR4 - SSD 256GB + HDD 1TB - LCD 15,6" FHD (3840x2160) LED IPS - GPU NVidia GTX1070 8GB DDR5) was placed approximately at 50 cm from the participant. Figure 2.3 (Panels A and B) shows a screenshot of the environment and its landmarks and the map with and without landmarks.

Figure 2.3. *Virtual environment: observer navigation view (2.3A) and sketch map with landmarks and the route (2.3B)*

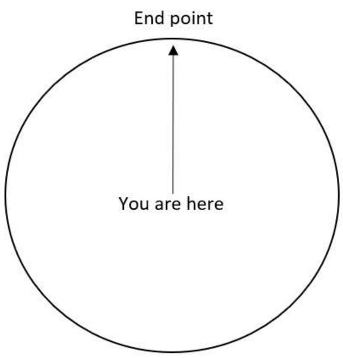
2.3A 2.3B

Note. 1 = grocery; 2 = bank; 3 = church; 4 = newsstand; 5 = flower shop; 6 = fountain; 7 = ice-cream shop; 8 = hotel; 9 = library; 10 = lunch bar; 11 = museum; 12 = hospital; 13 = sports hall; 14 = play park; 15 = pizza place; 16 = school; 17 = statue; 18 = theatre; 19 = post office.

Testing Phase

Pointing Task. The pointing task consists of imaging standing at the end point of the route previously learned, facing the last landmark encountered (lunch bar), and pointing at a third point (i.e., the starting point of the route). The answer was given in a circle on a sheet of paper in which the centre of the circle represents where the participant imagines themselves to stand and an arrow indicating the directions they are facing, and they draw another arrow indicating the starting point (Figure 2.4). The task consists of one item. The absolute degrees of error between the answers given by the participants and the right answer was calculated, ranging from a minimum of 0 to a maximum of 180 errors**.**

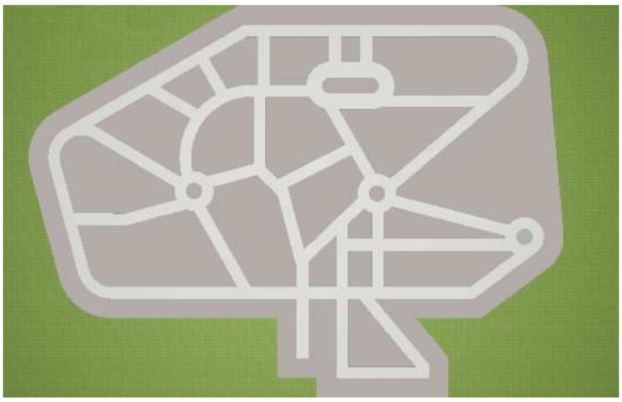
Figure 2.4. *Circumference used for the pointing task*



Map-completion Task. The map-completion task consisted of recalling and locating the landmarks in the sketch map. The latter consists of a sketch map of the environment without landmarks (Figure 2.5) on a sheet of paper (A4). As for the scoring, we assigned each landmark a score ranging from 0 to 1 based on the accuracy of the location. The scoring assigned zero points if the participant did not place the landmark in the correct grey portion; 0.5 points were awarded if the person located the landmark in the correct grey box but placed it incorrectly; and, finally, 1 point was awarded if the location was in both the correct grey portion and correct position within the portion (see Figure 2.5B for examples). The total score ranged from 0 to a maximum of 19 landmarks correctly located. Cronbach's alpha coefficient for the current sample was 0.83.

Figures 2.5. *Sketched map used in map-completion task (2.5A) and examples of scoring (0 point, 0.5 point, 1 point) for landmarks number 10 (lunch bar) in map-completion task (2.5B)*

2.5A



2.5B

2.2.3 Procedure

First, participants signed the informed consent form about the aims of the study, the duration of the study, and the participant's right to withdraw from it at any time. Then, participants completed the visuospatial tasks (Jigsaw Puzzle Test and Mental Rotation Test), and responded the Wayfinding Self-Efficacy Questionnaire. Afterwards, participants attended the virtual environment session: encoding and testing phases. First participants learned the route by actively navigating the environment with a joystick (encoding phase), then they performed the pointing task and the map-completion task in this order (testing phase). Recall tasks in testing phase had no time limits. Before each spatial recall task (pointing and map completion task) participants evaluate their task-specific self-efficacy. Each participant individually attended one session lasting around 1 h.

Before the virtual environment session participants had the opportunity to become familiar with the joystick and to practice navigation by moving within a simple virtual environment designed specifically for the training phase.

2.2.4 Statistical Analysis

Statistical analyses were performed using the Rstudio. Descriptive statistics of the whole sample are shown in Table 2.2. and divided for men and women are shown in Table 2.1. First of all, we ran correlation analysis, then, a structural equation model (SEM) was run to simultaneously analyse the relationship between gender, visuospatial cognitive abilities (considering the visuospatial working memory task [JPT] and mental rotation task [sMRT]), spatial self-efficacy (global and task-specific), and spatial recall tasks (pointing task and map-completion task) using the lavaan statistical package (Rossel, 2012).

As regard the SEM model, first, we create a single latent factor of visuospatial cognitive skills including the visuospatial working memory task (JPT) and mental rotation task (sMRT). We considered the ability to locate landmarks in a sketch map (map-completion task) and the ability to indicate the direction of the starting point of the route (pointing task) as dependent variables. In addition, we considered separately global spatial self-efficacy and task-specific spatial self-efficacy to investigate their distinct role in explaining environmental learning performance.

The model tested the following relationships: (a) the direct effect of gender on spatial recall task performance (Nazareth et al., 2019); (b) the direct effect of gender on global spatial self-efficacy (e.g., West et al., 2002) (c) the direct effect of gender on visuospatial cognitive skills; (d) the direct effect of global and task-specific spatial self-efficacy on spatial recall task performance (Pazzaglia et al., 2017, Pazzaglia et al., 2018); (e) the direct effect of visuospatial abilities on spatial recall task performance (Muffato et al., 2020).

Finally, it was assumed that spatial self-efficacy (global and task-specific) was a mediator of the relationship between gender and spatial recall task performance and that visuospatial cognitive abilities were expected to be another mediator of the relationship between gender and spatial recall task performance (e.g., Muffato et al., 2020). Lastly, we include the covariance between task-specific self-efficacies (pointing and map-completion) given the correlation between the two. Maximum likelihood method was used to estimate the model parameters and the following indexes to evaluate the goodness of the model: root mean square error of approximation (RMSEA); standardized root mean square residual (SRMR); comparative fit index (CFI); non-normed fit index (NNFI); and the Akaike information criterion (AIC). We used the following criteria to define good fit: nonsignificant χ^2, RMSEA < 0.05, SRMR < 0.05, CFI ≥ 0.97, and NNFI ≥ 0.97 (Joreskog & Sorbom, 1993).

First, we run the model including all hypothesized direct and indirect effects. Then, we followed a stepwise model-selection procedure to reach a final model in which we fixed nonsignificant path coefficients to zero one at a time. At each iteration, the path fixed to zero was the one that minimized the AIC index to the largest extent. Finally, 95% confidence intervals were calculated using bootstrap with 5000 iterations.

2.3 Results

Tables 2.1 and 2.2 provides descriptive statistics and bivariate correlations.

Figure 2.7 showed the initial model (Model 0) tested with all relationships included. The model showed good fit: χ^2 (11) = 9.72, p = .55, RMSEA = .00, SRMR = .03, NNFI = 1.01, CFI = 1.00, AIC = 2603.041, however, some paths were not statistically significant. Therefore, we fixed to zero some path (as described above) in order to improve the model based on the AIC and stepwise model-selection. In Figure 2.8, the final model showed confirmed good fit indices, χ^2 (17) = 15.38, p = .57, RMSEA = .00, SRMR = .05, NNFI = 1.01, CFI = 1.00, AIC = 2596.698.

Results showed a direct positive relationship between task-specific spatial self-efficacy and the map-completion task. A positive direct relationship emerged between global spatial self-efficacy and the pointing task. Moreover, a direct positive relation emerged between visuospatial cognitive abilities (visuospatial WM task [JPT] and mental rotation task [sMRT]) and the map-completion task. No direct relations emerged between task-specific spatial self-efficacy and visuospatial cognitive abilities with the pointing task.

Concerning the indirect effects hypothesized, we found that the relation between gender and the map-completion task was mediated by spatial self-efficacy (global and task-specific) ($\beta = -.04$, $p = .01$, 95% CI [-.08, -.01]). In addition, an indirect effect of gender on the map-completion task, mediated by visuospatial cognitive abilities ($\beta = -.23$, $p < .001$, 95% CI [-.35, -.13]). Finally, an indirect effect of gender on the pointing task mediated by global self-efficacy was $\beta = .04$, $p = .05$, 95% CI [.00, .09]).

Table 2.1. *Descriptive statistics divided for men and women*

	Men		Women	
	Mean	*SD*	*Mean*	*SD*
Pointing task	53.92	42.25	57.79	47.92
Map-completion task	8.23	4.27	5.98	3.76
JPT	24.69	4.63	22.30	4.34
sMRT	5.21	2.53	3.22	2.21
Self-efficacy (global)	26.45	4.75	24.76	5.53
Task-Specific Self-efficacy (map-completion task)	2.74	1.09	2.48	.95
Task-Specific Self-efficacy (pointing task)	3.40	.99	3.03	.96

Table 2.2. *Bivariate correlations (Pearson's coefficients) and descriptive statistics of the whole sample for all measures examined in the study (N = 173)*

	1.	2.	3.	4.	5.	6.	7.
1. Pointing task	-						
2. Map-completion task	-.22*	-					
3. JPT	-.14	.39***	-				
4. sMRT	-.07	.31***	.40***	-			
5. Self-efficacy (global)	-.19*	.30***	.12	.09	-		
6. Task-Specific Self-efficacy (map-completion task)	-.18*	.31***	.07	.15*	.39***	-	
7. Task-Specific Self-efficacy (pointing task)	-.14	.48***	.12	.05	.46***	.55***	-
Mean	56.41	6.79	23.16	3.93	30.32	2.57	3.14
SD	45.88	4.08	4.58	2.51	5.78	1.01	0.98

Note. JPT = Jigsaw Puzzle Test; sMRT= short Mental Rotations Test; * = $p < .05$; ** = $p <.01$; *** = $p < .001$

Figure 2.6. *Distributions of scores divided for men and women*

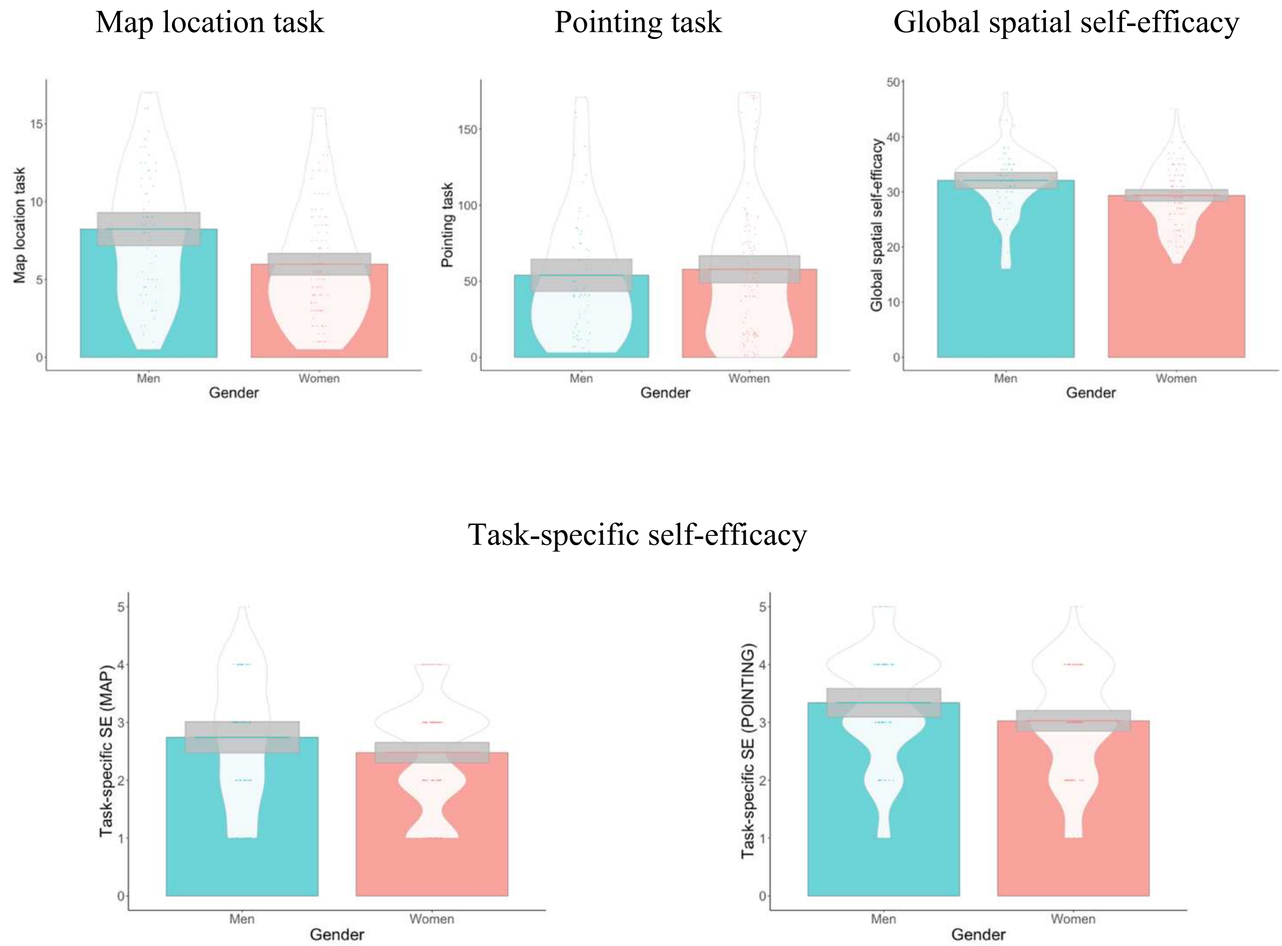


Figure 2.7. *Initial model tested with all the relationship*

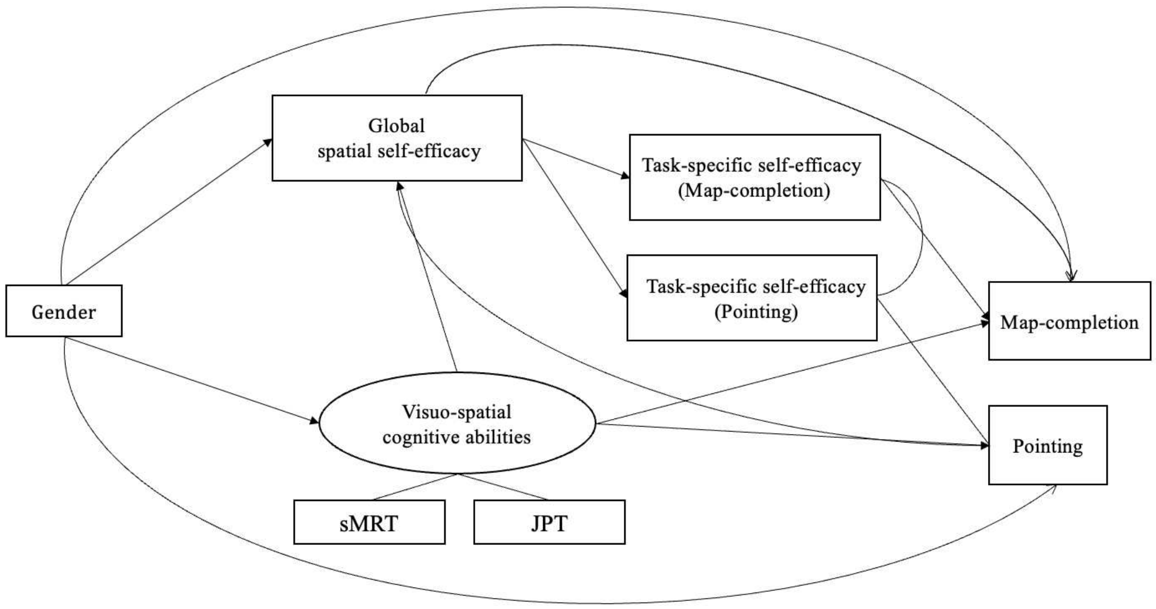
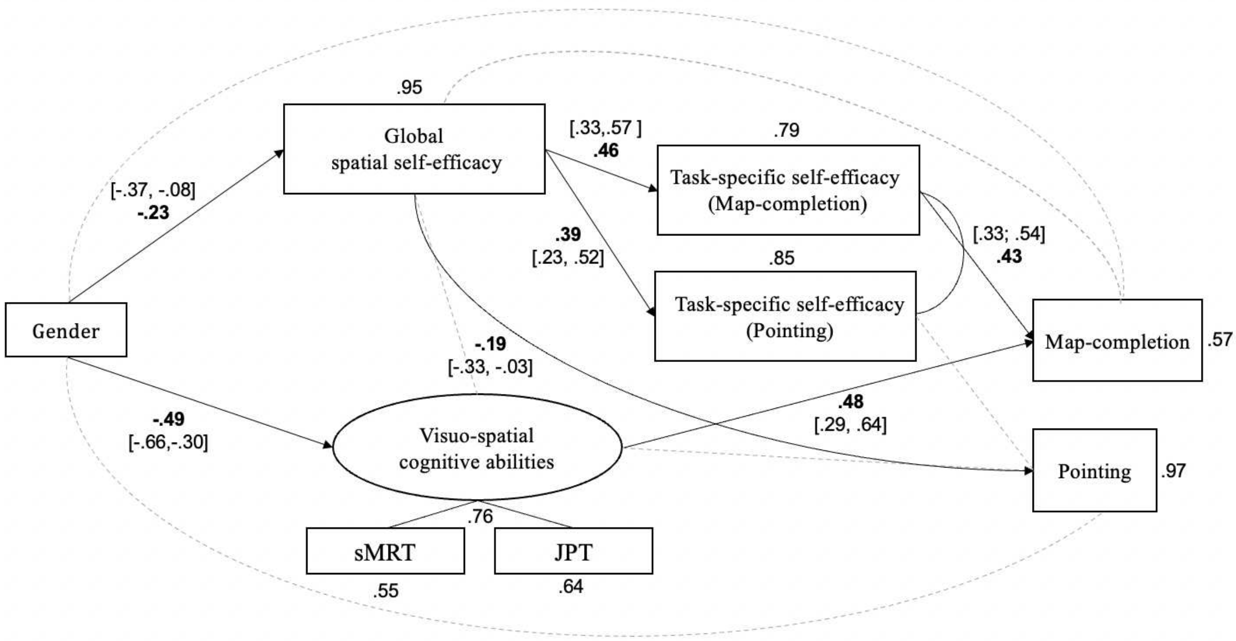


Figure 2.8. *Final model with standardized beta coefficients*



Note. Bold coefficients (and black paths) are statistically significant with $p < .05$; 95% CI are reported in brackets; grey paths were fixed to zero. The residual variance components for dependent variables indicate the proportion of unexplained variance.

2.4 Discussion

In this study, we used a structural equation model approach to investigate directed and mediated relationships between gender, visuospatial cognitive abilities, spatial self-efficacy, and spatial recall performance after the young adult participants learned a virtual environment. Moreover, we intended to explore how global and task-specific self-efficacy related to spatial recall performance after the participants learned a virtual environment.

The results from the final path model showed a significant positive association between global spatial self-efficacy and a pointing task and a significant positive association between global and task-specific spatial self-efficacy and a map-completion task. In line with previous evidence on finding shortcuts (Pazzaglia et al., 2018) we found a relationship between global spatial self-efficacy and the ability to indicate the direction of the starting point (pointing task) and newly detect a relationship between global and task-specific spatial self-efficacy and the ability to locate landmarks (map-completion task). These findings supported the idea that both beliefs about one's global ability in navigation and beliefs referring to a specific spatial task right before performing it are related to the acquisition of spatial knowledge from a new environment. Despite being expected, no association between task-specific spatial self-efficacy and the pointing task emerged. Because people are typically more familiar with maps than drawing directions within a circumference, in which an arrow represents the heading direction, it is possible that the pointing task—which entails drawing an arrow in a circumference—is less familiar than a task that presents a map of the environment. As a result, it can be more challenging for participants to evaluate their own level of self-efficacy when performing the pointing task. For this reason, the relationship between specific self-efficacy and pointing may be missing. A more cautious interpretation behind this lack of relationship is linked to the limited measured reliability. The pointing task, in contrast to the map-completion task, was made up of only one item, resulting in a possible limit to the accuracy of the measurement of the participants' ability to indicate directions in a virtual environment.

In sum, consistent with Bandura's (1989) self-efficacy theory, these results seem to suggest that individuals who believe in their abilities in environmental tasks obtained better spatial recall performances. This relationship could be explained by the fact that people with higher levels of self-efficacy are more likely to persist in the face of spatial tasks based on requests that differ from their learning (starting from the observer point of view) and that require them to work on representation (e.g., making an inference about a direction and visualizing it), as in the pointing and map-completion tasks.

Moreover, regarding the relationship between visuospatial cognitive abilities (mental rotation ability and VSWM) and environment learning, a strong relationship emerged between visuospatial cognitive abilities and the ability to locate landmarks in a map of the environment, confirming that both mental rotation abilities and VSWM support the formation of a spatial mental representation of the environment (Hegarty et al., 2006; Muffato et al., 2020). However, no association emerged between visuospatial cognitive abilities and pointing ability. As stated above, this result could possibly be linked to the characteristics of the pointing task, specifically to its limited reliability.

Finally, concerning the relationship between gender and spatial recall performance after learning a virtual environment, our results showed that the relationship was mediated by visuospatial abilities and spatial self-efficacy. In other words, we found that being a woman was negatively related to performance in visuospatial cognitive abilities and the latter was positively related to one's accuracy in locating landmarks on a sketch map. Furthermore, consistent with our hypotheses, we newly found that both global and task-specific spatial self-efficacy mediated the relationship between gender and the map-completion task. Therefore, being a woman was negatively related to spatial self-efficacy, and the latter was positively related to one's accuracy in locating landmarks on a sketch map. These results newly suggest that, rather than gender, lower spatial self-efficacy could be negatively related to the ability to form a mental representation of a new environment or that the relationship between gender and the ability to form a mental representation is attenuated by individuals' perceptions of self-efficacy. In summary, gender differences in spatial self-efficacy (and in visuospatial cognitive abilities) accounted for the relationship between gender and environment learning and its subsequent recall, suggesting their mediating role.

In conclusion, this study newly suggests that poorer performance in visuospatial abilities and lower self-efficacy than men about accomplishing spatial tasks (global and task-specific self-efficacy) might predispose women to feel less confident in learning a new environment due to the negative influence on their performance. Investigating individual spatial self-efficacy provided a better understanding and a delineation of the complexity of environment learning and its recall underlying gender differences in performance.

Based on the results of Study 1 highlighting the importance of not only visuospatial abilities (and therefore a cognitive component) but also spatial self-efficacy, in Study 2, we tried to combine these two aspects experimentally by manipulating self-efficacy during visuospatial tasks.

CHAPTER 3

STUDY 2. Environment Learning in a Virtual Environment: The Role of Self Efficacy Feedback and Individual Visuospatial Factors

3.1 Rationale and Aims of the Study[2]

As mentioned above, environment learning and its recall is a complex ability showing wide variability between individuals (Wolbers & Hegarty, 2010). Among the individual factors that can relate to environment learning, the role of visuospatial abilities and self-reported spatial measures are well-known and well-studied (Hegarty et al., 2006). Visuospatial abilities consist of mental rotation abilities, spatial visualization, and spatial perception (Linn & Petersen, 1985). The self-reported measures can include spatial inclinations such as a sense of direction and spatial anxiety (e.g., Meneghetti et al., 2014; Pazzaglia et al., 2018). Previous evidence has showed that both visuospatial abilities and self-reported measures are related to performance in environment learning and its recall, contributing to the explanation of its variance (Hegarty et al., 2006; Meneghetti et al., 2014, 2021).

As opposed to visuospatial abilities, self-reported measures have been studied less in relation to spatial cognition, and among those measures, spatial self-efficacy consists of a person's beliefs about their ability to accomplish spatial tasks (Bandura, 1977; Mitolo et al., 2015; Pazzaglia et al., 2017). In general, self-efficacy can be considered from a more global level (beliefs and individual perceptions about one's usual general spatial or memory abilities across many situations in various domains) or from a more task-specific and situational level (beliefs about one's ability to perform a specific task now; Hertzog & Dixon, 1994). Moreover, compared to perceived general cognitive ability or global self-efficacy, task-specific self-efficacy has been shown to relate more strongly to better cognitive performance on memory tasks (Beaudoin & Desrichard, 2011). For the

[2] Study 2 has been described in Miola, Muffato, Meneghetti & Pazzaglia (2021)

abovementioned reasons and in light of the results of Study 1, considering both global and task-specific beliefs is important when assessing self-efficacy.

Self-efficacy has been thoroughly studied, especially in the areas of academic motivation, sports performance, and health behaviors. In the spatial cognition domain, a few studies have showed that spatial self-efficacy is positively related to performance in shortcut finding (Pazzaglia et al., 2017, 2018). Moreover, so far, the role of spatial self-efficacy has been studied only at the correlation level, and no study has used a manipulation to experimentally investigate the effect of self-efficacy on spatial recall performance after the participants learned a virtual environment.

One way to manipulate self-efficacy is through normative feedback, such as presenting an individual with information on their performance compared to that of others. Evidence has suggested that positive normative feedback, even if fictitious and independent of a performance's effectiveness, can sustain performance in various subsequent kinds of tasks (e.g., arithmetic, name recall, or physical task), suggesting that fictitious positive normative feedback can be an effective intervention to promote self-efficacy (e.g., Peifer et al., 2020).

Study 2 aimed to investigate whether spatial self-efficacy manipulated through feedback could have an effect on spatial recall performance after the participants learned a virtual environment. More specifically, we investigated whether receiving positive normative feedback (as opposed to neutral feedback) about a visuospatial task performance affected the participants' subsequent spatial recall performance after they learned a virtual environment. The experimental manipulation consisted of showing the experimental group their scores and their levels in comparison to others after they completed three visuospatial tasks (experimental group) and showing another group neutral feedback about their completion status without further information (control group). Then all the participants were asked to learn a virtual environment and perform spatial recall tasks: route retracing, pointing, and map-completion task.

To further investigate the role of feedback, a second aim was to investigate whether receiving feedback on visuospatial tasks may have an indirect effect on the participants' subsequent spatial recall performance after they learned a virtual environment through the increase in their task-specific spatial self-efficacy. In other words, we investigated if positive normative feedback on visuospatial tasks could be related to self-efficacy in spatial recall performance and, in turn, if the latter could be related to spatial recall performance after the participants learned a virtual environment.

Finally, another aim was to investigate whether spatial self-efficacy (both global and task-specific) predicted the participants' spatial recall performance after they learned a virtual environment independently of the feedback condition and other individual spatial factors. After controlling for the manipulation, gender, and individual spatial factors (visuospatial abilities, sense of direction, and spatial anxiety), we investigated whether spatial self-efficacy was related to spatial recall performance after the participants learned a virtual environment. For this aim in this study specifically, we included other self-reported measures, such as sense of direction and spatial anxiety.

Hypotheses

- *Direct and Indirect Effects of the Feedback on Environment Learning*. We hypothesized that the group who received the positive normative feedback on the visuospatial task would perform better in spatial recall performance after learning a virtual environment than the who that did not (in line with previous findings using positive normative feedback; e.g., Wulf et al., 2010)

  In addition, we expected that receiving positive normative feedback could have an indirect effect on spatial recall performance after the participants learned a virtual environment. In line with previous finding on arithmetic and name recall tasks (Peifer et al., 2020; Strickland-Huges et al., 2017), we expected that receiving positive feedback on visuospatial tasks could relate to the participants' subsequent self-efficacy in environment learning and spatial recall performance. Therefore, we hypothesized that task-specific self-efficacy in environment learning and spatial recall performance could mediate the relationship between receiving positive normative feedback and spatial recall performance.

- *Individual Differences in Environment Learning*. Given the importance of task-specific self-efficacy in predicting performance (in the general memory domain; Beaudoin & Desrichard, 2011), we expected task-specific spatial self-efficacy to relate to spatial recall performance after accounting for the condition (receiving or not a feedback) and other individual factors (i.e., visuospatial abilities and self-reported measures).

3.2 Methods

3.2.1 Participants

A total of 231young adults (48% women) aged 18 to 40 were involved in the study (age mean = 23.85; *SD* = 4.06). All participants were native Italian speakers and volunteered to take part in the experiment. The study was conducted in accordance with the recommendations of the local university's research ethics committee (approval No. 3914). All participants gave written informed consent before and after the experiment. Each participant was told that the purpose of the research was to study the relationship between sense of direction, spatial self-efficacy, spatial anxiety, and learning a virtual environment. At the end of the experiment in addition, we gave a very detailed debriefing to the participant in which we resumed and deepened the aims, and both condition groups were told that the fictitious positive feedback given to the experimental group was expected to increase (compared to the control group with neutral feedback) its sense of self-efficacy and spatial performance, as well as determine whether increased self-efficacy corresponded to better performance in subsequent trials. Further, any additional information the participants would require was given, including their actual performance in the initial trials.

3.2.2 Materials

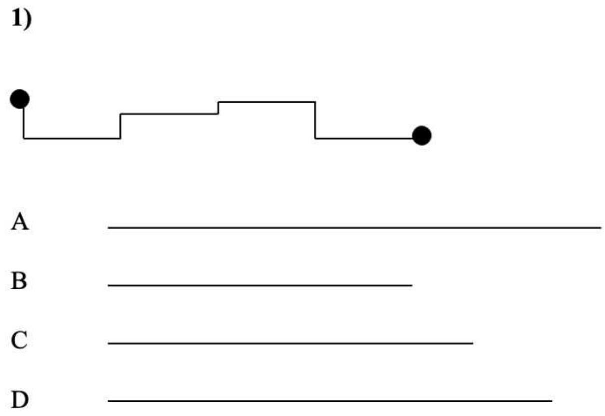
Visuospatial Cognitive Tasks and Spatial self-assessment measures

The following measures were used to perform basic visuospatial tasks, after which the participants received feedback. We selected the following visuospatial tasks so that it was difficult for a given participant to fully understand their own performance and comparison with others (e.g., we recorded the time taken to complete the tasks).

Route task (Nori & Giusberti, 2006). The route task is composed by one single item. A schematic map with a path outlined inside was presented to participants. Participants were required to imagine tracing the path from a first-person perspective and to describe aloud, as quickly as possible, which directions to take to reach the end point (i.e., go straight, turn right, turn left). Each correct answer was awarded 1 point, for a maximum of 17. During the test, times were recorded, but no time limit was given. The task evaluates participants' ability to switch from a map perspective (allocentric view) to an egocentric perspective.

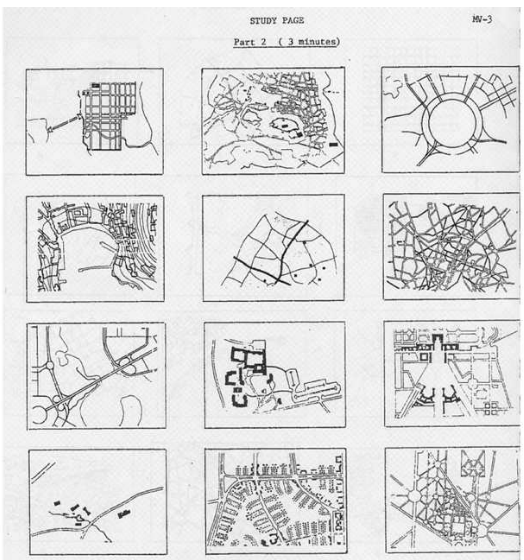
Survey Task (Nori & Giusberti, 2003). The survey task is composed by seven items. Two points (start and end points) joined by a series of segments were presented to participants. Participants were required to judge the distance between the two points, imagining the segment as straightened out and mentally adding the segments' length for a total of seven trials. In answering each question, participants chose from four alternatives (i.e., straight lines of different lengths). Each correct answer was awarded 1 point, for a maximum score of 7. This task aimed to evaluate the participants' ability to use allocentric coordinates.

Figure 3.1. *Example of the survey task*



Map memory (Ekstrom et al., 1976). The map memory tasks is composed by 24 item. First, 12 maps were shown to participants simultaneously. Each participant's task consisted of carefully watching and memorizing the maps for 3 minutes. Afterward, a page with different 12 maps was shown to the participant who was required to recognize those they had just studied and indicate which of the original maps were present. The task was composed of two trials. Each correct identification was scored as 1 point, for a maximum score of 24. This task aimed to investigate the ability to remember configurations of figural stimuli.

Figure 3.2. *Example of the map memory task*



Wayfinding Self-Efficacy Questionnaire (Mitolo et al., 2015; Pazzaglia et al., 2017). The questionnaire assesses global spatial self-efficacy. Each item presented an environmental spatial task, and the person indicate how confident individuals feel about their ability to perform the task described. It consisted of eight items scored on a 6-point Likert scale (1 = *not at all* to 6 = *very much*). The maximum score was 48. The Cronbach's alpha for the present sample was 0.81.

Task-specific spatial self-efficacy. Before each environmental task in virtual environment (see testing phase section), participants were asked to indicate how well they felt able to accomplish the spatial recall tasks there are going to perform (i.e., "Now that the task has been explained to you, how well do you feel you can do the task you are about to tackle?"). Participants assigned themselves a score on a scale of 0 to 100 (0 = *not at all* to 100 = *very much*). The scale was based on the guide for constructing self-efficacy scales (Bandura, 2006).

Sense of Direction and Spatial Representation Questionnaire (SDSR; Pazzaglia & Meneghetti, 2017). The questionnaire assesses sense of direction and spatial preferences. It consists of 14 items divided into three subscales: sense of direction and preference for survey representation (e.g., "Do you think you have a good sense of direction?"); knowledge and use of cardinal points (e.g., "When you are outside, do you naturally identify cardinal directions?"); preference for route and landmark mode (e.g., "Think about how you orient yourself in different surroundings). Respondents indicate their degree of agreement using a 5-point Likert scale (1 = *not at all* to 5 = *very much*). The maximum score was 70. The Cronbach's alpha for the present sample was 0.82.

Spatial Anxiety Scale (SAS; De Beni et al., 2014). The questionnaire assesses the degree of space-related anxiety experienced in an environment. It consisted of eight items (e.g., "going to an appointment in an unfamiliar part of the city") scored on a 6-point Likert scale (1 = *not at all* to 6 = *very much*). Participants' final score is the sum of their ratings for each item, with higher scores corresponding to greater spatial anxiety. The maximum score was 48. The Cronbach's alpha for the present sample was 0.81.

Virtual Environment and Spatial Recall Tasks

- **Encoding phase**

The same virtual environment presented in Study 1 was used in the present study with the difference being that people were seeing a video instead of actively navigating the environment with the joystick. Specifically, a video from a first-person perspective was created showing the approximately 1-km route within the environment that encountered all of its landmarks. Participants saw the video twice with instructions to watch carefully and learn the route, the environment, and all landmarks. The video lasted around 4 minutes, it was created at an eye height of 160 cm, and the camera was set with a horizontal field of view of 90°. The walking speed was 4 m/s.

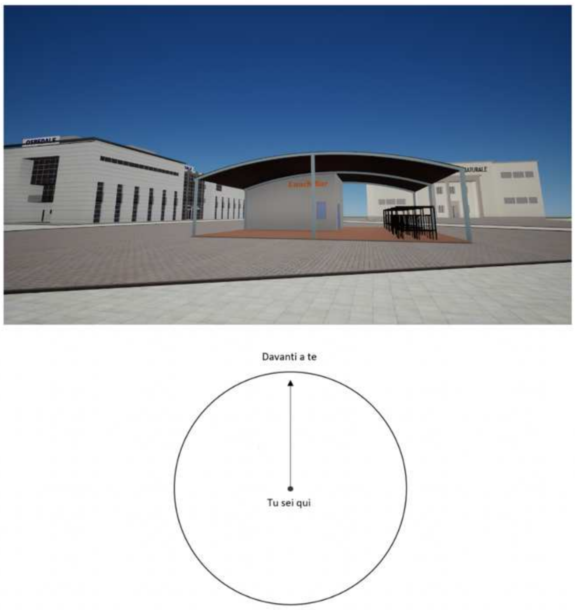
- **Testing phase**

Route direction task. In the route direction task participants see a screenshot representing an intersection of the streets on the previously seen path (see Figure 3.3 for an example). For each screenshot, was required to indicate the direction needed to proceed in order to retrace the route shown in the video by inserting an arrow inside the screenshot. The task contained eight items (screenshots of intersections) showed in a random order that were the same for all participants. One point was awarded for each correctly identified turn. The maximum score was 8.

Figure 3.3. *Example of item for route direction*

Pointing task. In the pointing task participants see a viewpoint in the environment (a screenshot) and indicate the direction of a target landmark in the environment that was not visible to them. The target landmarks were located behind, in front, and to the left or right of the participants' heading direction. The task consisted of six trials. Participants answered using a circle in which the center represented the place where the participant imagined they were standing, and an arrow indicated the direction they were facing, and they drew a second arrow indicating the direction to the target landmark. For each pointing task item, we calculated the absolute degrees of error between the answers given by the participants and the right answer, ranging from a minimum of 0 to a maximum of 180 degrees of error.

Figure 3.4. *Example of item for pointing task*



Map-completion task. In the map-completion task participants see a sketched map of the virtual environment without landmarks, and a list of numbered landmarks (see Figure 3.5). Participants were required to locate each landmark on the sketched map by writing its corresponding number. Each landmark position was in one of the gray areas of the map resulting from the intersections of roads in the road network. For each landmark positioned by participants, we assigned 0, 0.5 or 1 depending on accuracy of the answer (see Study 1 for an example). The maximum score was 19. Two independent judges scored participants' performance to obtain the final scores (sum of landmarks correctly located). Given the strong degree of accordance in their ratings (r_s = .99), the first judge's scores were used in the analyses.

Figure 3.5. *Map-completion task*

Self-efficacy manipulation

In the positive feedback condition, we gave feedbacks about participants performance after the three visuospatial tasks: route task, survey task and map memory tasks. Specifically, for each task, we displayed a high fictitious (but plausible) score and the corresponding indication that the participant's performance was above or significantly above average ("Rote task: performance above average; survey task: performance above average; Map memory task: performance definitely above average). Finally, a summary comment on participant's performance appeared at the bottom of the page that is "profile obtained: very good orientation abilities." The feedback was presented for a few minutes as needed for each participant to carefully read the scores and comments.

In the neutral feedback condition, we gave feedback about participants performance after the three visuospatial tasks: route task, survey task and map memory tasks. In this case, however, for each task, the computer displayed that the tasks had been completed, without any further information on the performance.

Concerning manipulation check, at the end of the experiment, participants in the positive feedback condition were asked (a) “Do you remember the feedback that has been given to you?” and (b) “Do you agree with the feedback?” to indicate how much they believed in the feedback. Participants responded on a 6-point Likert scale (0 = *not at all* to 5 = *very much*).

3.2.3 Procedure

The study was administered online (one session) using Qualtrics® and Google Jamboard® and Zoom® (from December 2020 to February 2021). First, participants signed an informed consent explaining part of the study aims and their right to withdraw at any time. After giving their consent, they provided some general details and answered three spatial self-assessment questionnaires on sense of direction (SDSR), spatial anxiety (SAS), and global spatial self-efficacy in a randomized order. Then, participants performed the three visuospatial tasks (route task, survey task, and map memory task) and were randomly assigned to the neutral or positive feedback conditions. Subsequently, a video of a route within the virtual environment was shown to the participants twice. Then, they performed the route-retracing task, the pointing task, and the map-completion task, in this order. Before each spatial recall task, participants were asked to evaluate how well they felt able to perform the task (task-specific self-efficacy). Finally, manipulation check questions and debriefing were administered at the end of the study session.

3.2.3 Statistical Analysis

First of all, before performing the analysis we examined the answers on manipulation check questions. 18 participants in the positive feedback condition did not agree with the experimental feedback, having rated the question “Do you agree with the feedback that has been given to you?” with *not at all*, *barely*, or *slightly*. Before removing the 18 participants, we checked whether they differed in terms of global spatial self-efficacy from the other participants. The three groups (1 = positive feedback, 2 = control, and 3 = 18 participants who did not agree with the feedback) did not show significant difference between each other (p > .06) in terms of global spatial self-efficacy. Therefore, we excluded the 18 participants. Thus, the final sample consisted of 213 participants: 99 participants in the positive feedback condition and 114 participants in the neutral feedback condition (see Table 3.1 for descriptive statistics).

To investigate the effect of self-efficacy manipulation on spatial recall performance we ran an ANOVA to examine differences between positive vs neutral feedback groups. Then, to further investigate the experimental manipulation of self-efficacy, we ran a mediation analysis using the Lavaan statistical package (Rossel et al., 2012) for each spatial recall task (route retracing, pointing, and map-completion). We simultaneously analyze the relationships among the experimental manipulation (condition), task-specific spatial self-efficacy, and spatial recall performance.

Finally, to study the relationships between individual spatial factors (visuospatial tasks and spatial self-assessments) and spatial recall task performance, we carried out generalized linear and binomial mixed-effect models on each spatial recall task (route retracing, pointing, and map-completion). Mixed-effects models allow us to take into account the repeated measures design of the experiment (i.e. items of each tasks) and participants were treated as random effects, with random intercepts that account for interpersonal variability. Continuous predictors were standardized. A stepwise approach was used in order to find the best model with lower AIC (Akaike Information Criterion). The same procedure was carried out for each spatial recall task. Specifically, predictors were added as follows: first, we considered a null model (m0) including only intercepts without predictors; second, we explored the manipulation of spatial self-efficacy such as the condition (m1); and, third, we considered sex to be related to spatial performance (m2; Nazareth et al., 2019). Afterward, we added the three measures of visuospatial abilities (m3, m4, and m5; Hegarty et al., 2006). Next, we added SAS (m6) and SDSR scores (m7; Lawton, 1994). Finally, after controlling for individual differences, we added global spatial self-efficacy (m8) and task-specific spatial self-efficacy (m9) to determine their relationships with spatial performances. We entered the predictors into the model one at a time and kept each predictor only if it decreased the AIC of at least two units

(Burnham & Anderson, 2010). If adding the predictor did not decrease the AIC, its presence was considered negligible, and it was not considered in the subsequent model.

3.3 Results

Table 3.1. *Descriptive statistics divided by groups*

	Positive feedback condition (N = 99)		Neutral feedback condition (N = 114)		Excluded Participants (N=18)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Age	24.06	3.84	23.93	4.48	22.28	1.41
Education						
Spatial Anxiety Scale (SAS)	20.43	5.49	21.49	6.17	25.72	6.61
Spatial self-efficacy (global)	32.02	4.50	30.31	5.69	28.83	6.22
Sense of direction (SDSR)	40.91	6.29	39.93	8.34	35.94	7.26
Task-Specific Self-efficacy (route retracing)	63.08	21.51	55.95	21.51	46.39	17.05
Task-Specific Self-efficacy (pointing task)	56.84	22.47	46.83	22.11	45.28	14.70
Task-Specific Self-efficacy (map-completion task)	55.72	23.10	47.97	22.90	35.00	22.03

Spatial self-efficacy manipulation

- *ANOVA results*

Table 3.2 shows the means and standard deviations of route-retracing task, pointing task, and map-completion task. Results from the ANOVA showed no differences in spatial recall tasks between the two groups, suggesting that the feedback did not produce direct differences in environment learning and subsequent spatial recall tasks.

Table 3.2. *ANOVA*

Variables	Positive feedback condition (N = 99)		Neutral feedback condition (N = 114)					
	M	*SD*	*M*	*SD*	F	*p*	η^2	η_p^2
Route retracing	6.46	1.20	6.70	1.26	2.132	0.146	0.01	0.01
Pointing	62.74	22.11	62.52	24.58	.005	.945	< .001	< .001
Map-completion	5.31	4.37	5.56	4.42	0.169	.681	< .001	< .001

- *Mediation models*

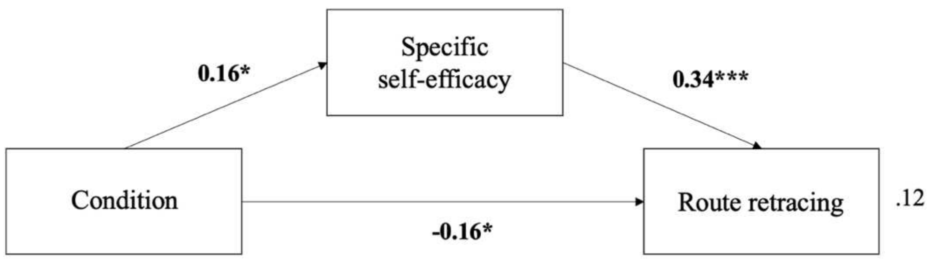
For each spatial recall task, we ran a mediation analysis considering participant condition (1 = neutral feedback, 2 = positive feedback) as the independent variable, task-specific spatial self-efficacy as a mediator, and performance in the spatial recall task as the dependent variable.

Route retracing. We found (a) a significant positive relation between participant condition and task-specific spatial self-efficacy ($\beta = .16$, $p = .02$), (b) a significant positive relation between task-specific spatial self-efficacy and route retracing ($\beta = .34$, $p < .001$), and (c) a significant negative relation between the condition and route retracing ($\beta = -.16$, $p = .02$). Finally, a significant positive indirect relationship between the condition and route retracing emerged through the mediation of task-specific spatial self-efficacy ($\beta = .05$, $p = .03$, a x b; see Figure 3.6). In other words, receiving positive feedback negatively affected route retracing performance and was mediated by task-specific spatial self-efficacy.

Pointing. We found (a) a significant positive relation between the condition and task-specific spatial self-efficacy ($\beta = .22$, $p = .001$), (b) a significant negative relation between task-specific spatial self-efficacy and pointing ($\beta = -.18$, $p = .008$), and (c) a nonsignificant positive relationship between the condition and pointing ($\beta = .04$, $p = .52$). Finally, a significant negative indirect relationship between the condition and pointing mediated by task-specific spatial self-efficacy emerged ($\beta = -.04$, $p = .04$, a x b; see Figure 3.7). In other words, receiving positive feedback negatively influenced pointing performance and was mediated by task-specific spatial self-efficacy.

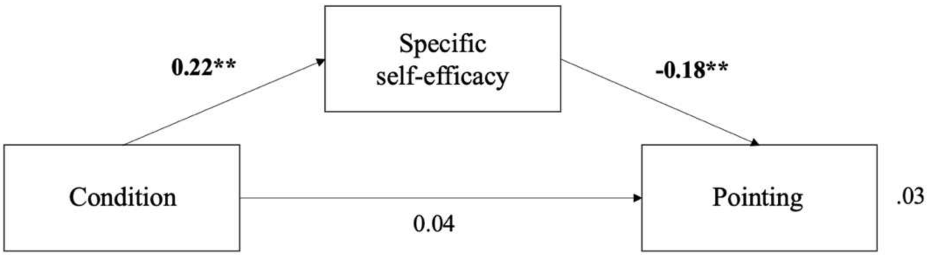
Map-completion. We found (a) a positive direct relationship between the condition and task-specific spatial self-efficacy (β = .16, $p = .02$), (b) a significant positive relation between task-specific spatial self-efficacy and map-completion (β = .36, $p < .001$), and (c) a nonsignificant negative relationship between the condition and map-completion (β = -.08, $p = .18$). Finally, a significant indirect relationship between the condition and map-completion emerged that was mediated by task-specific spatial self-efficacy (β = .06, $p = .03$, a x b; see Figure 3.8). That is, receiving positive feedback was negatively related with route-retracing performance and was mediated by task-specific spatial self-efficacy.

Figure 3.6. *Mediation models of the effect of positive feedback on performance in route retracing. *p < .05; **p < .01; ***p < .001.*



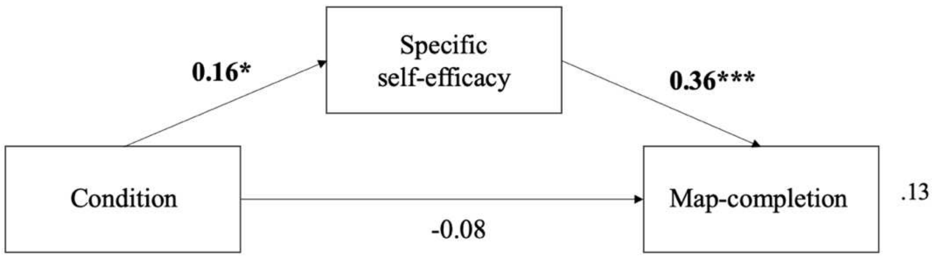
Note: condition: receiving a positive feedback vs receiving neutral feedback. The residual variance components for dependent variables indicate the proportion of unexplained variance

Figure 3.7. *Mediation models of the effect of positive feedback on performance in pointing. *p < .05; **p < .01; ***p < .001.*



Note: condition: receiving a positive feedback vs receiving neutral feedback. The residual variance components for dependent variables indicate the proportion of unexplained variance

Figure 3.8. *Mediation models of the effect of positive feedback on performance in map-completion. *p < .05; **p < .01; ***p < .001.*



Note: condition: receiving a positive feedback vs receiving neutral feedback. The residual variance components for dependent variables indicate the proportion of unexplained variance

Individual visuospatial factors and spatial recall tasks

- *Mixed models*

Tables 3.2, 3.3, and 3.4 show the results of model comparison relative to route-retracing, pointing, and map-completion tasks, respectively, following the model selection procedure explained in the Data Analysis section. We applied mixed linear and binomial models in which the condition (positive vs. neutral feedback), gender, visuospatial abilities tests, and self-reported measures were added, as all of these variables are related to spatial recall performance after learning in a virtual environment. Finally, global and task-specific spatial self-efficacy were added to investigate their influence after accounting for individual spatial factors and feedback.

For route retracing (see Table 3.2), the final model (m9) containing route task, map memory, and task-specific spatial self-efficacy showed a statistically significant effect of visuospatial abilities, such as route task (odds ratio [OR] = 1.28, 95%, confidence intervals CI [1.10, 1.48], p = .001), map memory (OR = 1.30, CI [1.12, 1.50], p < .001), and task-specific spatial self-efficacy (OR = 1.40, CI [1.20, 1.63], p < .001). Overall, the predictors explained 33% of the variance. The explained marginal variance was 6%.

For pointing (see Table 3.3), our final model (m7) containing route task, map memory, and sense of direction showed a statistically significant effect of visuospatial abilities, such as route task (β = -5.14, CI [-8.17, -2.11], p = .001), map memory (β = -3.71, CI [-6.76, -0.68], p = .017), and sense of direction (β = -4.78, CI [-7.82, -1.81], p = .002). Overall, the predictors explained 12% of the variance. The explained marginal variance totaled 3%.

For map-completion (see Table 3.4), our final model (m9) containing route task, survey task, map memory, spatial anxiety, sense of direction, and task-specific spatial self-efficacy showed statistically significant effects of route task (β = .04, CI [.01, .07], p = .004), map memory (β = .03, CI [.00, .06], p =.031), sense of direction (β = .03, CI [.00, .07], p = .029), and task-specific spatial self-efficacy (β = .06, CI [.03, .09], p < .001). Overall, the predictors explained 32% of the variance. The explained marginal variance totaled 6%.

Table 3.2. *Route retracing: stepwise model selection results. Variables that decreased AIC appear in bold.*

Model	Route Retracing	AIC
m0	Participant + item	1428
m1	+ Condition	1428
m2	+ Sex	1430
m3	**+ Route task**	**1418**
m4	+ Survey task	1420
m5	**+ Map memory**	**1401**
m6	+ Spatial anxiety (SAS)	1559
m7	+ Sense of direction (SDSR)	1559
m8	+ Global spatial self-efficacy	1403
m9	**+ Task-specific spatial self-efficacy**	**1385**

Table 3.3. *Pointing: stepwise model selection results. Variables that decreased AIC appear in bold.*

Model	Pointing	AIC
m0	Participant + item	13426
m1	+ Condition	13428
m2	+ Sex	13426
m3	**+ Route task**	**13416**
m4	+ Survey task	13416
m5	**+ Map memory**	**13411**
m6	+ Spatial anxiety (SAS)	13412
m7	**+ Sense of direction (SDSR)**	**13403**
m8	+ Global spatial self-efficacy	13405
m9	+ Task-specific spatial self-efficacy	13403

Table 3.4. *Map-completion: stepwise model selection results. Variables that decreased AIC appear in bold.*

Model	Map-completion	AIC
m0	Participant + item	3943
m1	+ Condition	3945
m2	+ Sex	3942
m3	**+ Route task**	**3939**
m4	**+ Survey task**	**3936**
m5	**+ Map memory**	**3928**
m6	**+ Spatial anxiety (SAS)**	**3925**
m7	**+ Sense of direction (SDSR)**	**3914**
m8	+ Global spatial self-efficacy	3914
m9	**+ Task-specific spatial self-efficacy**	**3902**

3.4 Discussion

The general aim of Study 2 was to investigate the influence of spatial self-efficacy on spatial recall performance after the participants learned a virtual environment. To address this issue, we used a paradigm employing normative feedback to investigate whether an experimental manipulation of spatial self-efficacy through feedback after visuospatial tasks would affect the participants' subsequent performance in a virtual environment. We hypothesized that the group receiving positive normative feedback after completing the visuospatial tasks would perform better in subsequent spatial recall performance after they learned a virtual environment. Furthermore, we hypothesized that task-specific spatial self-efficacy would mediate the relationship between receiving feedback and spatial recall performance after the participants learned a virtual environment (e.g., Peifer et al., 2020).

First, contrary to our expectations, we did not find differences between the positive and neutral feedback groups' performances on any of the spatial recall tasks. However, the results of a mediation analysis showed that receiving feedback was indirectly related to the participants' performance on all the spatial recall tasks, through task-specific spatial self-efficacy. In other words, receiving positive normative feedback was related to higher levels of self-efficacy in environment learning and spatial recall performance; in turn, the latter was positively related to performance on spatial recall tasks. These results seemed to suggest that giving feedback after the participants completed visuospatial cognitive tasks may have increased their subsequent beliefs in their abilities to accomplish spatial tasks and they may have been more likely to put additional effort into succeeding at similar or more complex tasks. This finding was consistent with a previous finding on arithmetic tasks (Peifer et al., 2020) and suggested a possible benefit of feedback working through a change in spatial self-efficacy.

In conclusion, the novelty of this study was to investigate experimentally the relationships between spatial self-efficacy on visuospatial abilities, and spatial recall performance after the participants learned a virtual environment. However, the effect of receiving positive feedback was detectable only through the mediation analysis (correlational), and no direct evidence emerged from a comparison of the groups. A possible explanation for the weak effect of the feedback could be that the normative feedback (such as “your performance is above average”) was not very strong and did not have a generalized effect on everyone, but only on those who accepted it: Only these individuals increased their sense of self-efficacy and consequently increased their performance. A methodological explanation might be involved also: The remote mode adopted in this study (due to the COVID-19 pandemic) may have negatively affected the credibility of the feedback.

Moreover, in the mediation analysis, we found a statistically significant negative relationship between receiving positive feedback and performance in route retracing. A possible explanation could be that, independently by task-specific spatial self-efficacy, receiving positive feedback could have convinced the participants that achieving the goal would be easy. In this case, when the difference between the goal and the perceived possibility of achieving the goal is small, a person will invest fewer resources and perform worse. In other words, it is possible that various people react differently to self-efficacy; for some, it raised self-efficacy to the point that they were motivated to work more on the task, while for others, it led to overconfidence.

Finally, another aim of this study was to investigate the role of spatial self-efficacy in spatial recall performance after participants learned a virtual environment, regardless of the experimental condition and other individual spatial factors. The results from mixed models showed that after we accounted for the manipulation of spatial self-efficacy and gender, the route and map memory tasks were significant predictors of performance in route retracing, pointing, and map-completion. Moreover, we found that task-specific spatial self-efficacy measured before each task constituted a statistically significant predictor of the participants' abilities to retrace a path (i.e., route retracing task) and to locate landmarks (i.e., map-completion task). These results indicated that among the self-reported spatial abilities, motivational factors such as self-efficacy could be involved in spatial recall performance. Furthermore, rather than global spatial self-efficacy in everyday spatial situations, the belief in one's ability to accomplish a task, taking into consideration the specific context in which the task takes place (i.e., task-specific spatial self-efficacy), is related to spatial recall performance after one learns a virtual environment. In addition to self-efficacy, sense of direction emerged as a significant predictor in the map-completion task, confirming its role in the ability to create a spatial mental representation of an environment.

CHAPTER 4

STUDY 3: Navigation Behavior in Men and Women: The Relationship Between Gender Stereotypes, Growth Mindset, and Spatial Self-Efficacy

4.1 Rationale and Aims of the Study[3]

In addition to environment learning, people may undertake everyday navigation behaviors when navigating in real environments. Indeed, people tend to explore their environments during navigation or, in contrast, rely on devices that use GPS (He & Hegarty, 2020). These two behaviors could have different effects in terms of success in environment learning and its recall because the exploration tendency seems to help people gain better survey knowledge of their environments (Gagnon et al., 2018; Meneghetti et al., 2014; Muffato et al., 2020), whereas the use of GPS seems to hamper environment learning (Dahmani & Bohot, 2020; Gardony et al., 2015; Ishikawa et al., 2008). However, even though GPS users seem to perform less accurately than people who directly navigate their environments or use physical maps (Ishikawa, 2019; Ishikawa et al., 2008), Nori et al. (2022) found that in the beginning, GPS use may enhance one's sense of direction.

Individual factors that may relate to navigation behaviors include individuals' beliefs about their spatial abilities (He & Hegarty, 2020), comprising spatial self-efficacy, growth mindset, and gender stereotypes. For example, concerning the malleability of spatial ability, a growth mindset consists of the belief that one can improve their spatial ability through personal effort or the use of strategies (Dweck, 2000; He & Hegarty, 2020). In general, adopting a growth mindset promotes functional motivation and behaviors that enhance individual performance or achievement (Dweck, 2000; Dweck & Yeager, 2019). In spatial cognition specifically, to the best of our knowledge, researchers have investigated the spatial growth mindset and its relationship with navigation behaviors in only one study. He and Hegarty (2020) hypothesized that people with growth mindsets,

[3] Study 3 has been described in Miola, Muffato, Meneghetti & Pazzaglia (under revision)

unlike those with fixed mindsets, would approach spatial situations in a different way: A greater growth mindset would result in a higher propensity for exploration and a decreased use of GPS. The results, however, did not support the hypothesis, and the growth mindset was weakly related to exploration tendency and GPS use, suggesting that other factors may intervene in the relationship.

Gender stereotypes consist of beliefs that women and men differ in certain abilities. Such beliefs can limit or sustain an individual's performance according to the stereotype threat and stereotype lift phenomena (Spencer et al., 1999; Steele, 1997).

In spatial cognition specifically, gender stereotypes seem to influence spatial performance. One study showed that after men and women were told they were likely to perform better, worse, or the same as groups of the opposite gender in navigation tasks, a stereotype effect occurred for men and women, especially in a more difficult task, and a second study showed that men performed better in a virtual navigation task in a stereotyped condition (thanks to a stereotype lift) than in a nonstereotyped condition (Allison et al., 2017; Rosenthal et al., 2012). Despite manipulation, whether gender stereotypes about spatial abilities affect men and women differently is still unclear.

A growth mindset, gender stereotypes, and spatial self-efficacy are the self-reported factors that have been initially identified in the research as affecting spatial performance (Allison et al., 2017; He & Hegarty, 2020; Pazzaglia et al., 2018). However, whether these beliefs may also be connected to navigation behaviors (i.e., exploration tendency and GPS use) is still unknown. Additionally, preliminary research has indicated that men and women hold different spatial self-efficacy beliefs and senses of direction, which suggested these variations may also exist in other spatial beliefs and may contribute to gender differences in navigation behaviors and ability (Nori & Piccardi, 2015; West et al., 2002).

Therefore, in Study 3, we aimed to investigate the pattern of relationships between beliefs about spatial abilities (i.e., gender stereotypes and growth mindset) and spatial self-efficacy and navigation behaviors (i.e., exploration tendency and GPS use) in men and women. Specifically, we investigated the relationship that the growth mindset and gender stereotypes have with navigation behaviors, examining spatial self-efficacy as a potential mediator. Finally, a secondary aim in this study was to examine gender differences in navigation behaviors and beliefs about spatial abilities.

Hypotheses

- *Growth Mindset, Spatial Self-Efficacy, and Navigation Behaviors*. Given that spatial self-efficacy is related to navigation performance (Pazzaglia et al., 2017, 2018), we believed that spatial self-efficacy could also be related to behaviors during navigation, including exploration tendency (positive relationship), and to GPS (negative relationship). Moreover, we proposed a conceptual model in which spatial self-efficacy mediated the association between the growth mindset and navigation behaviors. With the expectation that spatial self-efficacy would play a mediating role, we investigated how the growth mindset helped explain opposing types of navigation behaviors (i.e., exploration propensity and usage of GPS; in accordance with He & Hegarty, 2020). We based this hypothesis on a number of studies that demonstrated a relationship between the growth mindset and self-efficacy, with those who adopt growth mindsets apparently possessing greater self-efficacy (primarily in the area of academic achievement; e.g., Burnette et al., 2020; Chen & Pajares, 2010).
- *Gender Stereotypes, Spatial Self-Efficacy, and Navigation Behaviors*. Regarding the relationship between gender stereotypes and navigation behavior (i.e., exploration tendency and GPS use), we expected spatial self-efficacy to mediate the relationship. Given that spatial self-efficacy is related to performance (Pazzaglia et al., 2017) and is particularly lower in women (West et al., 2002), the role of spatial self-efficacy has been investigated to understand the mechanisms underlying the relationship between gender stereotypes and navigation behaviors.

  Even stereotypes can be related to self-efficacy. Indeed, the latter has been found to mediate the stereotype threat's effect on people's memory performance and academic achievement (Bouazzaoui et al., 2016; Chung et al., 2010). Accordingly, in the spatial cognition domain, we believed spatial self-efficacy might be related to the growth mindset and gender stereotypes concerning navigation performance.

- *Gender Differences***.** Since it has been shown that people consider a mental rotation task more masculine and men do better than women in the task (Halpern et al., 2010), we expected that men and women would report stronger beliefs in favor of men also in navigation ability. As West et al. (2002) found, we expected that women would report lower levels of spatial self-efficacy.

4.2 Method

4.2.1 Participants

A total of 609 participants (329 women) aged 18 to 50 years (mean 23.43 years, SD 5.32) were included in the study. All participants were native Italian speakers and volunteered to take part in the experiment and were recruited by word of mouth and through social networks. The study was conducted in accordance with the recommendations of the local university Research Ethics Committee (approval No. 3866). All participants were informed about the aims of the study and gave their written informed consent. Our sample size ensured that there were at least five observations for each parameter estimated, which is the minimum number of observations per parameter used in SEM (Bollen, 1989).

4.2.2. Materials

Wayfinding Self-Efficacy Questionnaire (spatial SE; Mitolo et al., 2015; Pazzaglia et al., 2017). See Study 1and 2.

Sense of Direction and Spatial Representation Questionnaire (SDSR; Pazzaglia et al., 2000; Pazzaglia & Meneghetti, 2017). See Study 1and 2.

Gender stereotype in navigation ability questionnaire (GSQ; adapted from Moè & Pazzaglia, 2006). The questionnaire assesses participants' beliefs about gender differences in spatial ability (e.g., “Orienting yourself in an unfamiliar environment" or “Finding your way on a map”). It consists of five items with which participants indicate how much they believe that men and women differ in the spatial tasks described, using a Likert scale (-3 = *women definitely do better* to + 3= *men definitely do better*). The total score ranges from -15 (stereotype in favor of women) to +15 (stereotype in favor of men). A higher score indicates a person more likely to believe that men are better in navigation and spatial ability. Cronbach's alpha for the current sample was 0.67 (the original version contained 7 items, 2 were removed due to the low reliability of the scale).

Growth mindset in navigation ability questionnaire (GMQ; translated from He & Hegarty, 2020). The questionnaire measures growth mindset with respect to navigation ability such as the belief that one's spatial navigation ability can be improved and changed. It consists of eight items on a 5-point Likert scale (1 = *not at all* to 5 = *very much*). Four items are incremental, so they are in favor of a growth mindset (e.g., "I can always substantially change my ability to navigate"); while four items are in favor of a fixed mindset (e.g., "I have a certain level of navigational ability and I cannot change it"). Scores on fixed items were reversed. To ensure a correct understanding of the term "navigation ability" before completing the growth mindset questionnaire participants were provided with a definition: "Navigation skill in the environment consists of the ability to move in the environment, to reach places and follow paths". The maximum score is 40. A higher score indicates a person more likely to believe that his/her navigation abilities can be improved. Cronbach's alpha for the current sample was 0.92.

Exploration tendency questionnaire (ETQ; translated from He & Hegarty, 2020). The questionnaire measures the tendency to explore environments and new routes during navigation. It consists of eight items, four are positively stated (e.g., "If I have a chance, I like to explore different routes to get to my destination"), and four are negatively stated (e.g., "I don't like to take a new route unless I have a friend with a good sense of direction guiding me") on a 7-point Likert scale to rate their agreement with these statements (1 = *completely disagree* to 7 = *completely agree*). A higher score indicates a person more likely to explore an environment. The total score is derived from the sum of the responses. The maximum score is 56. Cronbach's alpha for the current sample was 0.87.

Global positioning system use (GPS use). The questionnaire consisted in three items created *ad hoc* assessing participants' tendency to rely on devices and tool that use GPS: i) Do you consider the use of GPS/Google maps essential to get around? ii) How much do you use GPS/Google maps when moving to places you are unfamiliar with? iii) How much do you use GPS/Google maps to travel to places you know? Respondents answered on a 5-point Likert scale (1 = *not at all* to 5 = *very much*). The maximum score was 15 consisting in the sum of the scores. A higher score indicates a person more likely to rely on GPS during navigation. Cronbach's alpha for the current sample was 0.73.

4.2.3 Procedure

The study was administered online using Qualtrics® (from December 2020 to June 2021). All participants received a link and autonomously answered the online survey. First, participants signed an informed consent explaining part of the study aims and their right to withdraw at any time. After giving their consent, they provided general details such as age, sex, education. Then, the questionnaires on spatial self-efficacy, growth mindset, and navigation behaviors were presented in random order except for the questionnaire on gender stereotype in navigation abilities that was completed at the end of the survey to avoid activating any gender stereotype before completing other questionnaires. The study consists in one session lasting about 30 min. This study was part of a larger project including other measures beyond the scope of this paper and therefore not considered here.

4.2.4 Statistical Analysis

First, to investigate gender differences in spatial beliefs and navigation behaviors we run an ANOVA in all questionnaires, and we calculated the correlations between variables separately by gender. Then a path analysis was run with the Lavaan package (Rosseel, 2012) to investigate patterns of relationships between variables. Goodness of fit was assessed with the root-mean-square error of approximation (RMSEA), standardized root-mean-square residual (SRMR), comparative fit index

(CFI), non-normed fit index (NNFI), and Akaike information criterion (AIC; Akaike, 1974). The following criteria were used to define an acceptable fit: non-significant χ^2, RMSEA < 0.05, SRMR < 0.05, CFI ≥ 0.97, and NNFI ≥ 0.97 (Jöreskog and Sörbom, 1993).

To test our hypothesis, we run two model using Structural equation modelling (SEM). We first generate a single latent factor - called spatial self-efficacy - from the wayfinding self-efficacy questionnaire (global spatial self-efficacy), sense of direction and survey representation subscale of the SDSR (sense of direction), given their strong association. Then, the first model included growth mindset (GMQ) as a predictor, and exploration tendency (ETQ) and GPS use as dependent variables, finally spatial self-efficacy as mediator (Figure 4.2). The second model instead included gender stereotype (GSQ) as a predictor instead, and exploration tendency (ETQ) and GPS use as dependent variables; finally spatial self-efficacy as mediators (Figure 4.3). Each model was run controlling for age.

Subsequently, we used a multiple group approach to test whether the two models and their relationships differed significantly between men and women. We tested whether the regression coefficients differed between the two groups, comparing a model in which the parameters were constrained to be equal between the groups with a model in which they were not. Taking into account the fit criteria, AIC, and the test of the χ^2 difference, if the unconstrained model was better, it was adopted as the final, best model.

4.3 Results

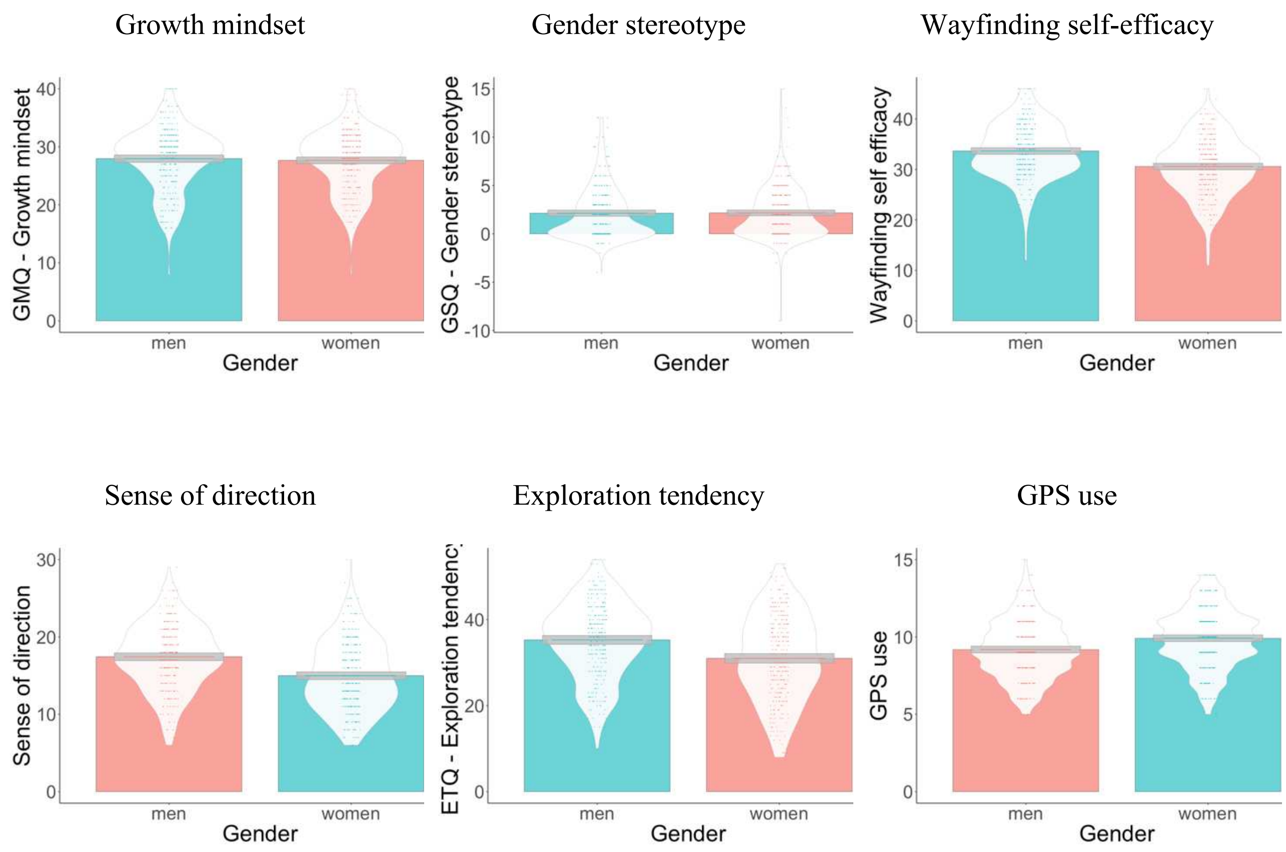
Gender differences in beliefs about spatial abilities and navigation behaviors (ANOVA)

Table 4.1 shows descriptive statistics and Figure 4.1 plots the distributions for beliefs about spatial abilities and navigation behaviors. A main effect for gender group was found for global spatial self-efficacy, sense of direction and survey representation subscale of the SDSR, GPS use, and exploration tendency (ETQ). The results showed that men scored higher than women on global spatial self-efficacy, sense of direction and survey representation subscale of the SDSR, and exploration tendency (ETQ). Moreover, men reported to use less GPS (see Table 4.1, and Figure 4.1).

Table 4.1. *Means, standard deviations and ANOVA statistics for study variables*

	Men (N=290)		Women (N=329)					
	M	*SD*	*M*	*SD*	F	*p*	η^2	η_p^2
Gender stereotype (GSQ)	2.13	2.73	2.16	2.62	0.017	.89	< .001	< .001
Growth mindset (GMQ)	27.95	5.46	27.66	5.19	0.47	.49	< .001	< .001
Global spatial self-efficacy	33.67	5.50	30.59	5.80	44.921	< .001	.069	.069
Sense of direction (SDSR)	17.43	4.23	14.98	4.50	47.478	< .001	.073	.073
Exploration tendency (ETQ)	35.30	8.79	31.01	9.98	31.447	< .001	.049	.049
GPS use	9.18	1.87	9.92	1.93	22.597	< .001	.036	.036

Figure 4.1. *Men and women's distributions for study variables*



- *Correlations*

Table 4.2 shows the correlations separately for men and women.

The results showed a statistically significant relationship between growth mindset (GMQ) with sense of direction (SDSR), global spatial self-efficacy and exploration tendency (ETQ), in both men and women. Furthermore, a negative relationship emerged between growth mindset (GMQ) and GPS use in both men and women. No relationship emerged between growth mindset (GMQ) and gender stereotype (GSQ) in men or women.

Concerning gender stereotype different correlations emerged in men and women. In women, gender stereotype (GSQ) was negatively associated with spatial global self-efficacy, sense of direction and survey representation subscale of the SDSR, and exploration tendency (ETQ). In men, gender stereotype (GSQ) correlated positively with spatial global self-efficacy and sense of direction and survey representation subscale of the SDSR.

Table 4.2. *Correlations between variables in men and women.*

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
1. Gender stereotype (GSQ)	-	-.06	-.20***	-.15**	-.13*	.04
2. Growth mindset (GMQ)	-.05	-	.21***	.29***	.26***	-.12*
3. Sense of direction	.13*	.13*	-	.71***	.49***	-.47***
4. Global spatial self-efficacy	.21***	.23***	.69***	-	.49***	-.47***
5. Exploration tendency (ETQ)	.04	.22***	.47***	.41***	-	-.32***
6. GPS use	-.04	-.22***	-.37***	-.36***	-.35***	-

Note: Men's correlations are shown below the diagonal (in grey); women's correlation are shown above the diagonal. * $p < .05$, ** $p < .01$, *** $p < .001$

- *Structural Equation Modelling (SEM)*

To investigate further the relationships between variables based on our hypothesis, we tested the two models shown in Figures 4.2 and 4.3. First, we created the latent variable (labeled "spatial self-efficacy") composed of the Wayfinding Self-Efficacy Questionnaire and the subscale of the SDSR (sense of direction and survey representation).

Because growth mindset and gender stereotype were not related with each other, we ran two separate models to investigate the relationship between each of them and the other variables in men and women. Both models showed good standardized fit indices, Model 1: $\chi^2(3) = 14.061$, RMSEA = .08, SRMR = .02, NNFI = .94, CFI = .99; Model 2: $\chi^2(3) = 6.525$, RMSEA = .04, SRMR = .01, NNFI = .98, CFI = 1.

Then, we refitted each initial model as a multi-group to compare regression coefficients for men and women. Regarding Model 1 (Figure 4.2), the fit was poorer for the model with constrained coefficients between the groups, $\chi^2(17) = 41.225$, RMSEA = .07, SRMR = .04, NNFI = .95, CFI = .97, AIC = 13,567.033, and better for the unconstrained model, χ^2 (6) = 14.870, RMSEA = .07, SRMR = .02, NNFI = .95, CFI = .99, AIC = 13,562.677. An χ^2 test that was performed to see whether the pattern of the relationship differed between the groups showed that the difference was statistically significant, $\chi^2(13) = 26.36$, $p = .0057$

As for Model 2 (Figure 4.3), the fit was poorer for the model with constrained across-group coefficients, $\chi^2(17) = 49.890$, RMSEA = .08, SRMR = .06, NNFI = .93, CFI = .96, AIC = 13,612.024, and better for the unconstrained model, χ^2 (6) = 9.161, RMSEA = .04, SRMR = .01, NNFI = .98, CFI = 1, AIC = 13,593.294. A χ^2 test showed the difference was statistically significant, $\chi^2(13) = 40.729$, $p < .001$. In short, the models in which the relationships were not constrained to be equal for men and women were better, so the regression coefficients are shown separately by gender in Figures 4.2 and 4.3.

Among each model, we tested the indirect effects of growth mindset (Model 1) and gender stereotype (Model 2) through the mediation of spatial self-efficacy on orientation behaviors. For Model 1, we found a statistically significant indirect effect of growth mindset on exploration tendency mediated by spatial self-efficacy in both men and women (women: $\beta = .17$, $p < .001$, 95% CI [.10, .25]; men: $\beta = .10$, $p <=.003$, 95% CI [.03, .15]). We also found an indirect relation between growth mindset and GPS use mediated by spatial self-efficacy in both men and women (women: $\beta = -.18$, $p < .001$, 95% CI [−.26, −.10]; men: $\beta = -.08$, $p < .01$, 95% CI [−.13, −.03]).

For Model 2, we first found an indirect effect between gender stereotype and exploration tendency mediated by spatial self-efficacy in both men and women (women: $\beta = -.12$, $p = .039$, 95% CI [−.20, −.05]; men: $\beta = .11$, $p = .033$, 95% CI [.03, .16]). We also found an indirect effect between gender stereotype and GPS use mediated by spatial self-efficacy (women: $\beta = .12$, $p = .002$, 95% CI [.05, .19]; men: $\beta = -.09$, $p = .006$, 95% CI [−.14, −.02]).

Figure 4.2. *Model 1: Final multi-group path model in the two groups with standardized coefficients. The coefficients on the left are for men; those on the right are for women.*

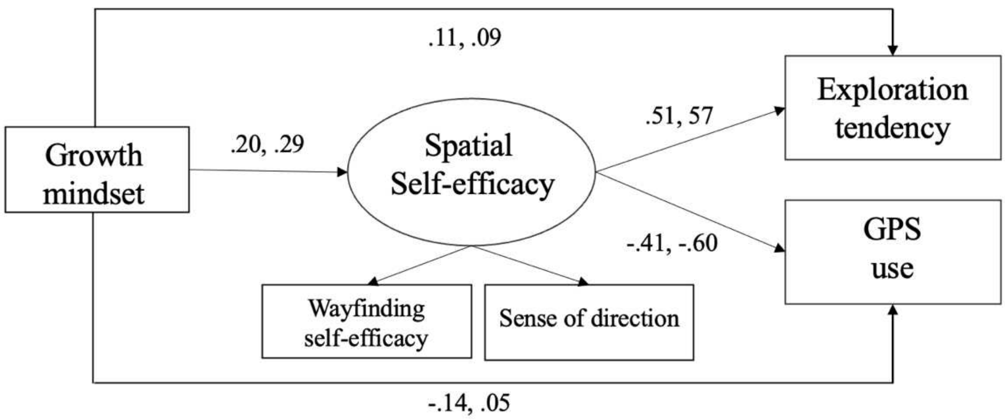
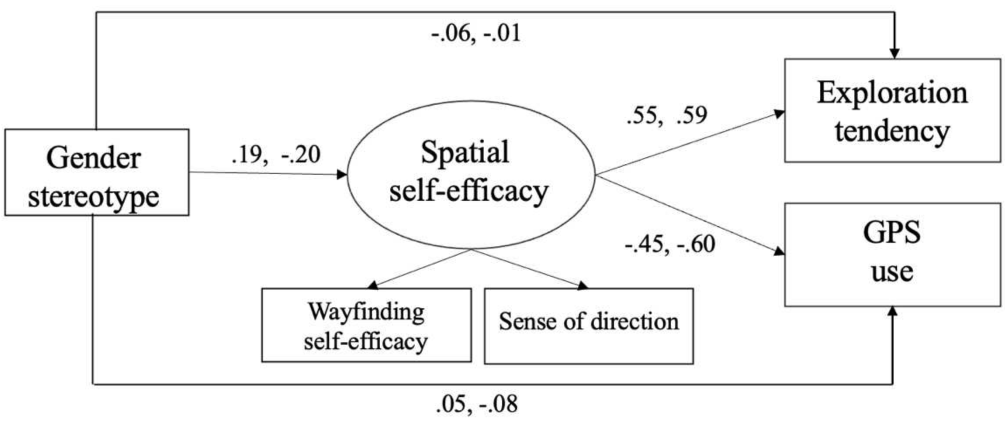


Figure 4.3. *Model 2: Final multi-group path model in the two groups with standardized coefficients. The coefficients on the left are for men; those on the right are for women.*



4.4 Discussion

In Study 3, we aimed to examine the relationship between beliefs about spatial abilities (i.e., growth mindset and gender stereotypes) and navigation behavior, specifically spatial efficacy's mediating role. The second aim was to investigate gender differences on beliefs about spatial abilities and navigation behaviors.

First, we discovered an association between people's spatial self-efficacy and the ways they navigate environments (i.e., navigation behaviors). Indeed, the more effective and confident people feel while navigating, the more they enjoy exploring their environment and the less they use GPS. These new findings expanded the relevance of spatial self-efficacy beyond performance in spatial tasks to include behaviors during navigation.

Moreover, one of the novelties of our results concerned the relationships between the growth mindset, gender stereotypes, and spatial self-efficacy. The results showed that the growth mindset correlated positively with global spatial self-efficacy in men and women, as seen in other domains (e.g., Chen & Pajares, 2010). These findings indicated that in the spatial cognition domain, the more people believe in their ability to improve their spatial abilities, the greater their perceived self-efficacy when they are navigating. In short, having incremental beliefs was associated with men's and women's beliefs in their abilities in spatial tasks.

Furthermore, we found a mediating role of spatial self-efficacy (variable comprising global spatial self-efficacy and sense of direction) between the growth mindset and navigation behaviors (i.e., exploration tendency and GPS use) for both genders. In other words, believing that their abilities can be improved and having greater self-efficacy during navigation may help people explore their environment more and use GPS less frequently.

Concerning gender stereotypes, the results showed opposite relationships in men and women with global spatial self-efficacy. The belief in men's superiority in spatial tasks was negatively associated with a global spatial self-efficacy in women and positively in men. Therefore, the more women believed in the stereotype in favor of men, the lower their self-reported self-efficacy in navigating and vice versa for men.

Furthermore, we found that spatial self-efficacy mediated the relationship between gender stereotypes and navigation behaviors (i.e., exploration tendency and GPS use) in men and women. These findings emphasized the importance of self-efficacy, and albeit cautiously, given the study's correlational nature, they suggested that supporting a stereotype that favors men can make women less motivated and inclined to explore their surroundings while making men more inclined to do so.

Regarding gender differences, aligning with the work of West et al. (2002), we found that women reported having a weaker spatial self-efficacy, suggesting they were less confident when judging their abilities to accomplish spatial tasks. Furthermore, we discovered that men and women differed in their navigation behaviors: Women were reportedly less inclined to explore their environment and more likely to use GPS than men when navigating. Finally, no difference emerged for growth mindset and gender stereotypes. Concerning gender stereotypes, some considerations are interesting about score distributions. Our results showed that men and women tended to hold similar gender stereotypes slightly in favor of men (with a mean around 2.00 in a range from −15 [strong stereotype in favor of women] to +15 [strong stereotype in favor of men]), indicating that men are slightly better navigators than women.

As a result, this study offers evidence that people's navigational habits are associated with their confidence in and beliefs about their spatial abilities (such as growth mindset and gender stereotypes). Men and women also appear to navigate their environments differently and have different levels of spatial self-efficacy. These findings shed light on the mechanisms that are probably responsible for the performance gaps between men and women.

CHAPTER 5

STUDY 4. Gender Differences in Learning a Virtual Environment: Examining the Relationship Between the Task Type and Beliefs About Spatial Ability

5.1 Rationale and Aims of the Study

The literature seems to have suggested that the effect of gender on environment learning and its recall may depend on the type of spatial knowledge tested; in fact, better performance by men appears to occur primarily in tasks that require survey knowledge (processing location and paths using an environment-based perspective, e.g., Castelli et al., 2008; Tlauka et al., 2015). Given the complexity of spatial knowledge and different patterns of men and women's performance, considering the various components of spatial knowledge is important when studying individual differences and gender in navigation ability.

In this regard, van der Ham and colleagues (2020) proposed a task battery to assess various components of participants' spatial knowledge according to Claessen and van der Ham's classification (2017). The classification suggested a differentiation between spatial domains of knowledge relating landmarks (knowledge about "what" there is in an environment), locations (knowledge about "where" are elements), and pathways (knowledge about "how to get there") (van der Ham et al., 2020). They also considered various frames of reference. Landmarks and locations can be coded and recalled using both the observer's based (location-egocentric knowledge) and the environment-based frame of references (location-allocentric knowledge; Burgess, 2006). Instead, pathways can be encoded considering a succession of objects observed along the way (path-route knowledge), as well as the connections between objects as visible on a map (path-survey knowledge; Taylor & Tversky, 1992). We used Claessen and van der Ham's classification and tasks in this study to measure environment learning and spatial recall performance comprehensively and to examine gender differences in landmark, location, and path knowledge, considering various perspectives (survey [allocentric] vs. route [egocentric]).

Furthermore, as previously suggested, in addition to task type and gender, there are beliefs about spatial abilities that are related to spatial recall performance. Among these factors, recent evidence has suggested that beliefs about spatial abilities (e.g., self-efficacy, gender stereotypes, and growth mindset) affect navigation ability and spatial recall performance (e.g., Allison et al., 2017; He & Hegarty, 2020; Pazzaglia et al., 2017). To date, how these beliefs can explain gender differences and how they are related between each other in predicting spatial recall performance after one learns a virtual environment remains unclear. Understanding self-reported beliefs about navigation ability (measured explicitly through questionnaires) can allow researchers to have a better picture of why men and women may differ in certain spatial tasks. Therefore, this study's aim was twofold.

First, we investigated whether gender differences were affected by the type of spatial knowledge tested after environment learning and by individual factors. Based on Claessen and van der Ham's (2017) classification, we used five tasks to investigate whether landmark, path, and location knowledge (survey [allocentric] or route [egocentric] perspective) were more or less sensitive to gender's effects. Based on several studies (e.g., Boone et al., 2018; Castelli et al., 2008), we expected that men would outperform women in tasks requiring survey knowledge. In addition, we investigated gender differences in beliefs about spatial abilities, such as spatial self-efficacy (and its source, mastery experience), the growth mindset, and gender stereotypes. Researchers have infrequently explored the differences between men and women in their beliefs about spatial abilities (e.g., mastery experience, growth mindset and gender stereotype). Furthermore, in this study, we measured spatial self-efficacy and gender stereotypes specifically related to the five tasks we proposed to gain a task-specific measure of self-efficacy and gender stereotypes (Hertzog & Dixon, 1994). We obtained a measure especially relevant to the task provided in this study in addition to general beliefs about spatial abilities assessed through questionnaires to explore gender differences.

Second, we aimed to study task-specific spatial self-efficacy, mastery experience, the growth mindset, and gender stereotypes in relation to each other and to various types of spatial knowledge. Specifically, we examined whether self-efficacy's in accomplishing a performance in a specific context (environment learning) was related to global beliefs about spatial ability, such as mastery experience, the growth mindset, and gender stereotypes. In other words, we investigated how self-efficacy, before the participants performed spatial recall tasks, interacted with beliefs about spatial ability (i.e., mastery experience, growth mindset, and gender stereotypes) in influencing performance in environment learning and subsequent recall.

Hypotheses

- *Gender Differences in Environment Learning and Spatial Beliefs*. We expected lower performance by women in survey tasks (i.e., location allocentric task and path survey task) since men seem to complete them better and seem to favor survey or allocentric strategies when learning an environment (e.g., Boone et al., 2018; Castelli et al., 2008; Coluccia & Louse; 2004; van der Ham et al., 2020).

  In addition, we expected women to report lower levels of task-specific self-efficacy before and after each spatial recall task based on prior research on global measures of self-efficacy (West et al., 2002). We anticipated lower levels of mastery experience, a growth mindset, and greater gender stereotype effects in women.
- *Relationships Between Beliefs About Spatial Abilities and Environment Learning*. Given the relationship between spatial self-efficacy and the growth mindset and stereotype found in the previous study (study 3), we hypothesized interactions between task-specific spatial self-efficacy in predicting spatial recall performance after one learns a virtual environment. We expected to find a relationship between task-specific spatial self-efficacy with mastery experience, the growth mindset, and gender stereotypes, especially in more complex tasks (i.e., survey tasks), as previously suggested (Pazzaglia et al., 2017).

5.2 Method

5.2.1 Participants

A total of 150 participants (98 women) participated in the study, ranging in age from 16 to 50 years (M = 27,113; SD = 8.00). We recruited participants through a social media posting of the study link and using the PROLIFIC platform. Among the sample, we recruited students from the University of Leiden through the SONA system platform and gave them two credits for participating in the study. The origin of the participants varied mainly from the Netherlands, the United States, Canada, England, Africa. The local ethical committee at Leiden University approved this study in accordance with the Declaration of Helsinki (2013). Before the online experiment began, each participant provided informed consent.

5.2.2 Materials

Questionnaires

For the assessment of growth mindset and gender stereotype we used the same questionnaires presented in Study 3: **Growth mindset in navigation ability questionnaire** (GMQ; He & Hegarty, 2020) and **Gender stereotype in navigation ability questionnaire** (GSQ; adapted from Moè & Pazzaglia, 2006). See study 3 for descriptions.

Mastery experience questionnaire (MEQ; *ad hoc*). The Mastery Experience Questionnaire is an ad hoc questionnaire consisting of eight self-reported items measuring judgments of competence that of one's own previous attainment in a spatial-related task. An example is "I always found my way to an appointment in the area of a city or town with which I was not familiar." Participants indicated their degree of agreement on a 5-point Likert scale ranging from 1 (*not at all*) to 5 (*very much*). We reversed the score on two items. The total score was the sum of the answers, and the maximum score was 40. The Cronbach's alpha coefficient for this sample was .72.

Single Items Before and After the Spatial Recall Tasks

Task-Specific Spatial Self-Efficacy. The participants assessed their own task-specific self-efficacy before and after each spatial recall task. Specifically, after the participants read the instructions for the environment recall task and before performed the task, we asked them a specific self-efficacy question to assess their confidence in performing the task we had just explained to them ("Now that the task has been explained to you, how well do you feel you can perform the task you are about to face in comparison to other people?"). The participants responded by placing a mark on a ruler between 0 (on the left of the ruler, indicating *much worse*) to 100 (on the right of the ruler, indicating *much better*). The center (50) indicated a neutral response. The same question was repeated for each task, for a total of five questions, before the participant performed the task.

After each task, the participants again rated their performance compared to other people in general ("How do you think you performed in comparison to other people?"). The participants responded by placing a mark on a ruler between 0 (on the left of the ruler, indicating *much worse*) to 100 (on the right of the ruler, indicating *much better*). The center (50) indicated a neutral response. The same question was repeated for each task, for a total of five questions, after the participant performed the task.

Task-Specific Spatial Gender Stereotypes. The participants assessed their task-specific gender stereotype beliefs after each spatial recall task. After each task, the participants rated their performance compared to people of their gender and the opposite gender by answering the following questions: (a) "How do you think you performed in comparison to the average female/male participant?" and (b) "How do you think you performed in comparison to the average female/male participant?" The participants responded by placing a mark on a ruler between 0 (on the left of the ruler, indicating *much worse*) to 100 (on the right of the ruler, indicating *much better*). The center (50) indicated a neutral response. The same two questions were repeated for each task, for a total of 10 questions. We combined the men's and women's scores to create a measure of gender stereotypes for comparison to the opposite sex.

Virtual Environment and Spatial Recall Tasks

We used the same virtual environment presented in Studies 1 and 2 in this one. In the learning phase, each participant watched the same first-person video of someone traveling a route approximately 1 km long in a virtual environment. After the learning phase, the participant completed five tasks designed to assess distinct domains of navigation ability: landmark task, location egocentric task, location allocentric task, path route task, and path survey task. Each task was described using a sample item with the corresponding correct response.

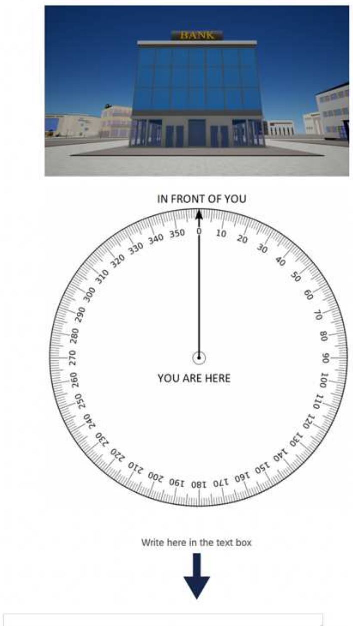
- **Testing phase**

Landmark Task. We showed the participants two images of the same landmarks in the environment from two points of view. One point of view was seen during the learning phase (watching a video) while the other was never seen by the participant. The task consists in identifying the landmark's facade they have seen while learning the route. The landmark task contained seven items. The participant earned one point for each correct answer and zero points for wrong answers. Figure 5.1 presents a sample item.

Figure 5.1. *Example of item of landmark task*

Location Egocentric Task. We showed the participants a landmark in the environment, and the corresponding task involved indicating the direction of a second landmark. The participants therefore imagined standing at one point in the environment and indicated the direction to a second point in the environment. The participant answered with a circumference shown to them within which they indicated the direction to the requested point. The circumference reproduced the area where the participant was (the center of the circle) and toward where they were looking (the picture at the top of the circle). The answer consisted of the number corresponding to the direction of the required landmarks shown in the circumference. For this task, we calculated the error as absolute degrees between the participant's answer and the right answer, ranging from 0 to 180. Figure 5.2 presents a sample item.

Figure 5.2. *Example of item of location egocentric task*

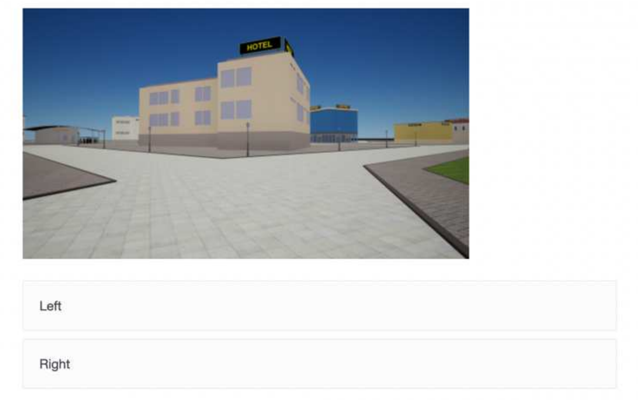


Location Allocentric Task. We showed the participants an image representing a landmark together with a map of the environment, with the starting point highlighted and four possible locations indicated with the letters A, B, C, and D. We asked the participants to indicate in which of the four locations the landmark was positioned by choosing the corresponding letter. They earned one point for each correct answer and zero points for wrong answers. Figure 5.3 presents a sample item.

Figure 5.3. *Example of item of location allocentric task*

Path Route Task. We showed the participants images of the environment representing street intersections. The task involved indicating in which of two directions they should proceed to retrace the previously learned route watched in the video. They earned one point for each correct answer and zero points for wrong answers. Figure 5.4 presents a sample item.

Figure 5.4. *Example of item of path route task*



Path Survey Task. We showed the participants three landmarks simultaneously. The task involved indicating the two landmarks of the three that were closer to each other. The participants earned one point for each correct answer and zero points for wrong answers. Figure 5.5 presents a sample item.

Figure 5.5. *Example of item of path survey task*

5.2.3 Procedure

The study consisted of a single online session on Qualtrics XP software. First, the informed consent form explaining the study's aims, tasks, and confidentiality agreement appeared. Once the participant provided consent, they answered a few questions to provide general information (age, gender, education, etc.). Then two questionnaires on spatial beliefs appeared in random order, measuring the participants' growth mindset in spatial ability and mastery experience in spatial ability.

In the second part of the session, the participants attended the virtual environment section in Qualtrics. First, they watched the video in a virtual environment twice. Then they performed the following environment recall tasks: (a) landmark task, (b) location egocentric task, (c) location allocentric task, (d) path route task, and (e) path survey task presented in a randomized order. Before and after each task, the participants respond to ad hoc questions about the tasks (for a total of four questions for each task). At the end of the experiment (to avoid stereotype induction), the participants completed the Gender Stereotype Questionnaire. The online survey took approximately 40 min to complete.

5.2.4 Statistical Analysis

First, we compared the men's and women's performances in spatial recall performance and self-reported measures using ANOVA. Then we compared models to investigate how task-specific spatial self-efficacy interacts with mastery experience, the growth mindset, and task-specific gender stereotypes with respect to different spatial knowledge. We carried out generalized mixed-effect linear and binomial regression models on landmark, path route, path survey, location egocentric, and location allocentric tasks. Using mixed-effects models, we took into account the experiment's repeated-measure design (i.e., items for each task). We treated the participants as random effects, with random intercepts that account for interpersonal variability. We standardized continuous predictors and used an Akaike information criterion-based stepwise approach to find the best model with the lowest Akaike information criterion for each spatial recall task.

5.3 Results

- *Gender differences in spatial recall tasks and beliefs about spatial abilities (ANOVA analyses)*

Table 5.1 shows descriptive statistics and ANOVA results; Figure 5.6 and 5.7 plots the score distributions for spatial recall tasks and beliefs about spatial abilities. Results showed a statistically significant differences in Mastery experience (MEQ) and growth mindset (GMQ) and in the performance of landmark task. Men outperformed women in landmark task and refers higher mastery experience and growth mindset compared to women.

Table 5.1. *Differences in means for all variables between men and women*

	Men (n=52)		Women (n=98)					
	M	*SD*	*M*	*SD*	F	*p*	η^2	ηp^2
Landmark task	**5.40**	**.91**	**4.98**	**.97**	**6.730**	**.01**	**.043**	**.043**
Path route	5.21	1.29	5.22	1.26	.004	.95	>.001	>.001
Path survey	3.58	1.78	3.44	1.55	.126	.72	>.001	>.001
Location egocentric	452.19	180.5	456.23	169.77	.018	.89	>.001	>.001
Location allocentric	3.75	1.8	3.19	1.76	3.344	.07	.022	.022
Mastery experience	**29.33**	**4.31**	**26.82**	**5.73**	**7.666**	**.006**	**.049**	**.049**
Growth mindset	**27.83**	**5.48**	**24.22**	**7.2**	**9.94**	**.002**	**.063**	**.063**
Gender stereotype	1.27	4.71	0.79	4.96	.334	.56	.002	.002
Task-specific self-efficacy (before tasks)	50.87	23.562	44.127	16.878	4.09	. 05	.027	.027
Task-specific self-efficacy (after tasks)	43.97	21.527	39.02	16.57	-1.43	.15	-.27	.002
Task-specific gender stereotype (opposite sex)	208.12	110.11	198.72	93.81	.21	.64	.001	.001

Figure 5.6. *Men and women's distributions of scores in the spatial recall tasks*

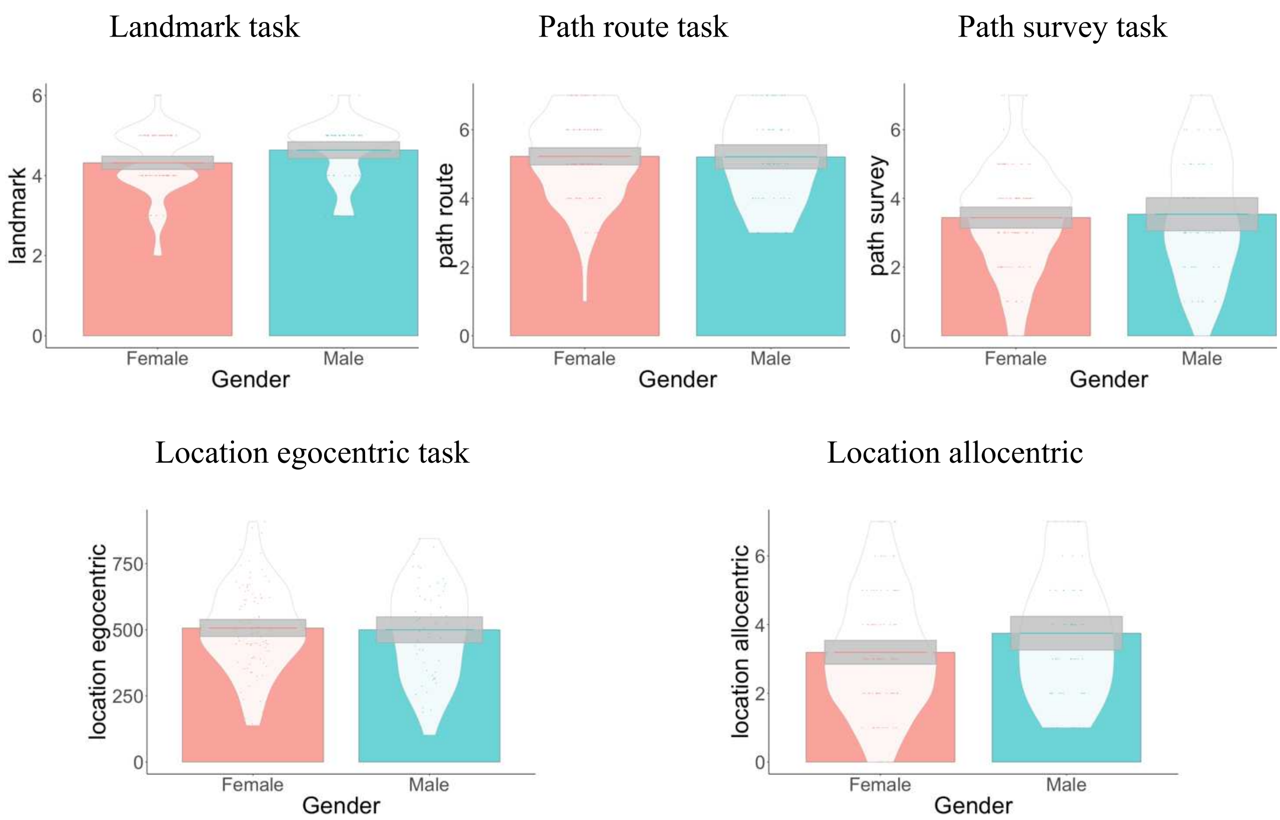
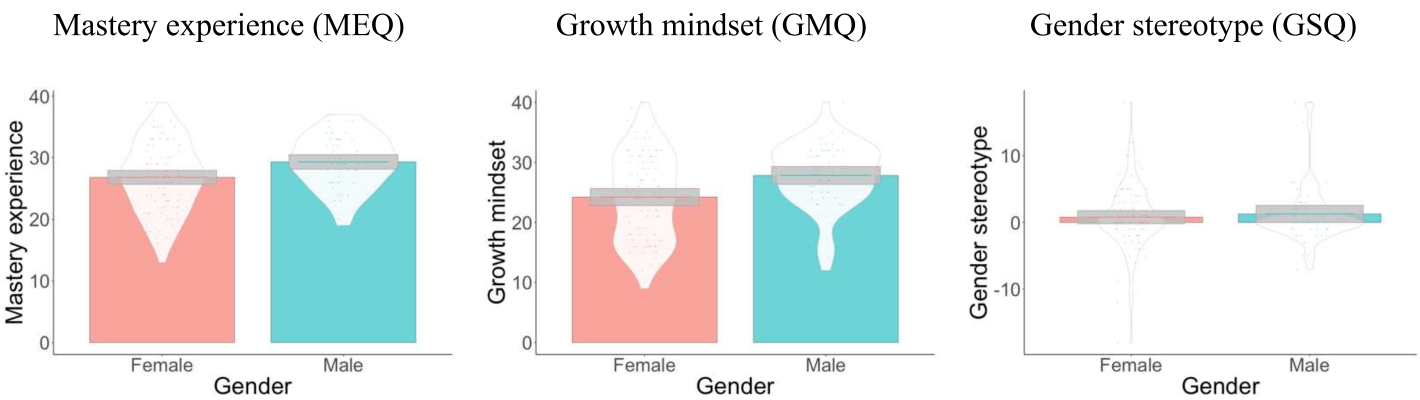
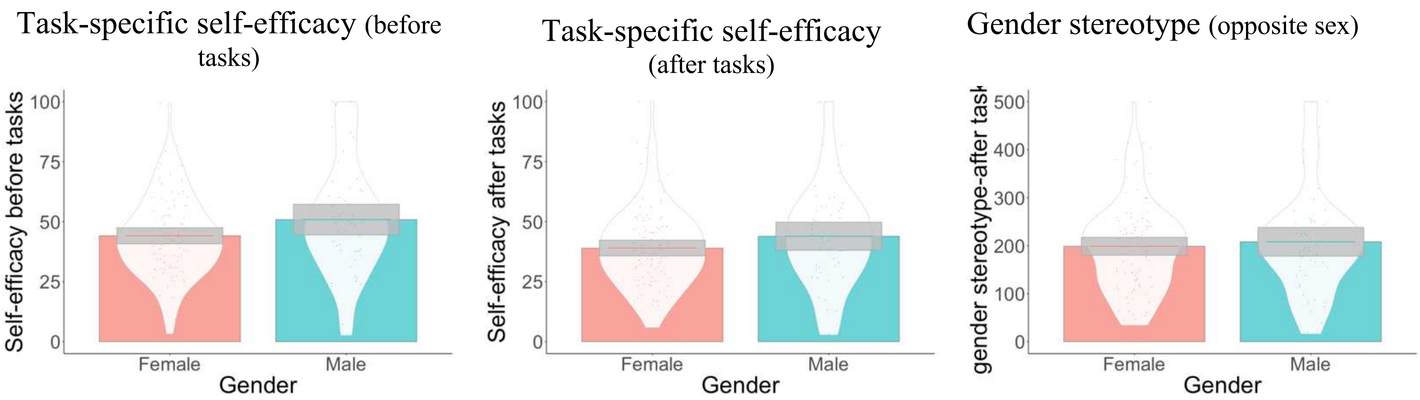


Figure 5.7. *Men and women's distributions of scores in the questionnaires*





- *Relations between beliefs about spatial abilities and spatial recall tasks (Mixed Models)*

Five models were run relative to the subsequent dependent variables: a) landmark task, b) route-retracing, c) route survey, d) location egocentric, e) location allocentric and following the model selection procedure explained in the statistical analysis section.

The results showed a statistically significant effect of gender stereotype in path route task (OR = 1.55, CI [1.20 – 2.00], *p* =.001]). Overall, the predictors explained 28% of the variance in path route task performance. The explained marginal variance totaled 3%.

For landmark task and path survey no statistically significant predictors emerged. The predictors however explained 37% of the variance for landmark task and 12% for path survey. The explained marginal variance totaled 1% for landmark task and 2% for path route.

For location egocentric we found that mastery experience (β = -4.64, CI [-8.80, -0.47], *p*= 0.029), and the interaction between task-specific spatial self-efficacy and mastery experience (β = -4.12, CI [-7.91, -0.47], *p* = 0.029) and between task-specific spatial self-efficacy and gender stereotype (β = 4.83, CI [1.76, 7.90], *p* = 0.002) were statistically significant predictors. Overall, the predictors explained the 14% of the variance and the marginal variance totaled 3%. See Figure 5.8.

Concerning the performance in location allocentric task mastery experience (OR = 1.35, CI [1.10, 1.64], *p* =.003), task-specific spatial self-efficacy (OR = 1.32, CI [1.06, 1.64], *p* =.014) and the interaction between task-specific spatial self-efficacy and mastery experience (OR = 1.49, CI [1.24, 1.80], p <0.001) were statistically significant predictors. The predictors explained the 21% of the variance and the marginal variance totaled 7%. See Figure 5.9.

Figure 5.8. *Interaction effects for location egocentric task performance*

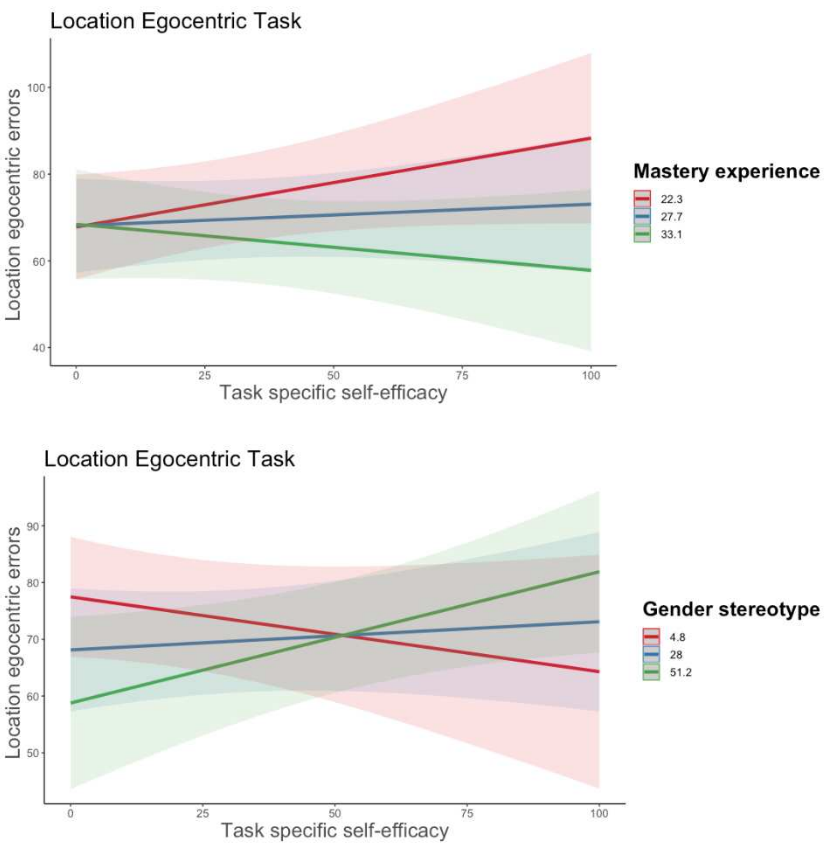
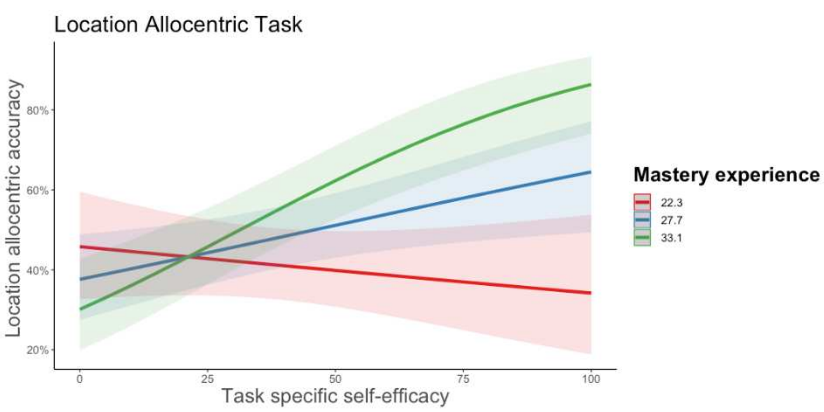


Figure 5.9. *Interaction effects for location allocentric task performance*



5.4 Discussion

In this study, we investigated gender differences in five spatial recall tasks after the participants learned a virtual environment to obtain a comprehensive measure of differences between men and women in environment learning and its recall. As previously suggested, we expected better performance by men in survey tasks (e.g., Castelli et al., 2008; van der Ham et al., 2020); moreover, we expected that spatial self-efficacy before and after tasks would be higher for men based on their performance. The results showed that men performed better than women only in landmark tasks; therefore, men seem better at recognizing landmarks than women, even from a nonlearning perspective.

Furthermore, no differences emerged in self-efficacy before and after each environment recall task. These findings suggested that women not only perform on par with men in spatial recall tasks (except in the landmark task), at least in our sample, but also seem not to consider themselves less effective before and after spatial recall tasks in a virtual environment (task-specific spatial self-efficacy). In sum, the gender differences found here were limited and did not seem to depend on type of perspective used (survey [allocentric] vs. route [egocentric]) or self-efficacy before tasks that required the participants to use multiple perspectives.

Concerning beliefs about spatial abilities, we found that women tended to report lower growth mindsets and less mastery experience in spatial ability in general (self-efficacy source). Therefore, it seems that women believe less strongly than men in the possibility of improving their spatial abilities and referred to have less success in environmental tasks in everyday life. Here, no differences emerged in gender stereotypes, but the averages for both groups were above zero (i.e., slightly in favor of men)

Finally, to investigate further how spatial self-efficacy was related to spatial recall performance after the participants learned a virtual environment, we explored whether self-efficacy before the participants performed the task (task-specific spatial self-efficacy) interacted with beliefs about spatial ability. To address this question, we used a mixed-models approach to investigate the relationship between task-specific spatial self-efficacy and (a) mastery experience, (b) the growth mindset, and (c) task-specific gender stereotypes in influencing spatial recall performance after the participants learned a virtual environment. We hypothesized that task-specific spatial self-efficacy would interact with beliefs about spatial abilities, especially in more complex tasks, such as survey tasks (Pazzaglia et al., 2017).

First, we found that task-specific spatial gender stereotypes predicted performance in path route tasks. This finding showed that one's belief that they performed a path route task better than the opposite sex group is positively related to their spatial recall performance. To date, the relationship between gender stereotypes and spatial recall performance has been studied mainly using experimental manipulations of gender stereotypes instead of measuring it explicitly (Allison et al., 2017; Rosenthal et al., 2012).

Second, task-specific spatial self-efficacy and mastery experience were significant predictors in egocentric and allocentric locations, respectively. In particular, mastery experience was associated with fewer errors in the egocentric task, whereas spatial self-efficacy before the task was associated with higher accuracy in the allocentric task.

Furthermore, we found interactions between beliefs about spatial ability. For the allocentric location and the egocentric location performance, an interaction between task-specific spatial self-efficacy and mastery experience emerged. Judgments of previous spatial experiences and self-efficacy before the spatial recall task contributed to better performance on the egocentric and allocentric location tasks. These findings add knowledge to the literature on self-efficacy and environment learning by showing that not only are the confidence and self-efficacy perceived before performing the task important (Beaudoin & Desrichard, 2011; Pazzaglia et al., 2017), but the set of successes and interpretations of our previous experiences in spatial situations also play a role in helping us in subsequent performances.

Interestingly, a statistically significant interaction emerged between self-efficacy before the task and task-specific gender stereotypes in location (egocentric) performance. In this case, the interaction was different from the previous one. Although self-efficacy and mastery experience contribute to better performance and their effect in interaction is therefore multiplicative/cumulative, here, the interaction went in a different direction. Self-efficacy before the participants performed the task was positively associated with performance among those with little belief in gender stereotypes.

This study's novelty stems from its linkage of various types of beliefs in spatial abilities to each other and in relation to environment learning, objectively measured through a proposed new classification (Claessen & van der Ham, 2017; van der Ham et al., 2020). In addition, it provides insights into what aspects may underlie gender differences in spatial learning by helping explain the variety of processes involved in this important skill for everyday life.

CHAPTER 6

General Discussion and Conclusions

6.1 Summary of the Findings

The general aim of this PhD dissertation was to investigate the relationships between beliefs about spatial abilities (i.e., spatial self-efficacy, growth mindset, and gender stereotypes), visuospatial abilities, navigation behaviors (i.e., GPS use) and navigation ability (i.e., spatial recall performance after the participants learned a virtual environment). Furthermore, we examined gender differences in navigation ability and beliefs about spatial abilities. In this context, we designed and conducted four studies aiming to:

i) Study the relationships between gender, visuospatial abilities (i.e., mental rotation ability and VSWM), global and task-specific spatial self-efficacy, and spatial recall performance after the participants learned a virtual environment (i.e., map-completion task and pointing task).

ii) Examine the direct and indirect effects of positive normative feedback on visuospatial tasks in subsequent spatial recall performance after the participants learned a virtual environment (i.e., map-completion task, pointing task, and route retracing task).

iii) Explore how the patterns or relationships between beliefs about spatial abilities (i.e., spatial self-efficacy, growth mindset, and gender stereotypes) and navigation behavior (i.e., exploration tendency and GPS use) are different for men and women and examine gender differences in beliefs about spatial abilities and navigation behaviors.

iv) Investigate how beliefs about spatial abilities and genders related to different spatial recall tasks after the participants learned a virtual environment, according to van der Ham and Claessen's (2020) classification.

To address these issues, alongside the dissertation's studies, the participants responded to questionnaires on spatial self-efficacy, the growth mindset, and gender stereotypes about spatial abilities and completed visuospatial tasks. Moreover, in Study 3, the participants evaluated their navigation behaviors (i.e., everyday behaviors in terms of exploration tendency and GPS use). Finally, in Studies 1, 2, and 4, the participants learned a virtual environment and performed several spatial recall tasks. The virtual environment used in this dissertation was built by professionals from the Department of General Psychology, University of Padova.

A schematic summary of the findings is provided below.

- Study 1, considering 173 young adults (64% women), showed that both global and task-specific self-efficacy were related to spatial recall performance after the participants learned a virtual environment (i.e., map-completion and pointing tasks). Moreover, gender was related to spatial recall performance after the participants learned a virtual environment (map completion task) through the mediation of spatial self-efficacy (global and task-specific) and visuospatial abilities.

- Study 2, considering 213 young adults (48% women), showed that the experimental manipulation of self-efficacy after the participants completed visuospatial tasks was positively related to task-specific self-efficacy in environment spatial recall and, in turn, the latter was positively related to performance in spatial recall tasks after the participants learned a virtual environment. Moreover, after we accounted for visuospatial abilities and self-reported measures (sense of direction, spatial anxiety, and global spatial self-efficacy), task-specific spatial self-efficacy emerged as a significant predictor in spatial recall tasks after the participants learned a virtual environment (i.e., route retracing and map-completion tasks).

- Study 3, considering 609 young adults (48% women), showed that spatial self-efficacy mediated the relationship between the growth mindset and navigation behaviors (i.e., exploration tendency and GPS use). Furthermore, spatial self-efficacy mediated the relationship between gender stereotypes and navigation behaviors. Women showed lower levels of global spatial self-efficacy and exploration tendency and higher GPS use.

- Study 4, considering 150 young adults (65% women), showed that task-specific spatial self-efficacy was related to mastery experience and gender stereotypes in predicting spatial recall performance after the participants learned a virtual environment. Women showed lower levels of mastery experience and the growth mindset and performed worse than men on a landmark task.

Across all four studies, our findings concerning spatial self-efficacy are consistent with each other and with previous initial evidence (e.g., Pazzaglia et al., 2017, 2018). Indeed, taken together, the results showed that spatial self-efficacy was related to spatial recall performance after the participants learned a virtual environment, suggesting that believing in the possibility of accomplishing a spatial task was associated with an individual's effective performance in environmental situations. More specifically, in Study 1, we found that global and task-specific self-efficacy were related to spatial recall performance in the ability to create a mental representation of the environment (i.e., map-completion and pointing tasks). These results were in line with previous findings on wayfinding tasks (finding a shortcut; Pazzaglia et al., 2017) but extended the knowledge to tasks adopting egocentric (pointing task) and allocentric (map-completion task) perspectives, bringing out the importance of spatial self-efficacy in different types of spatial knowledge.

Furthermore, in Study 2, we found that among the self-reported measures, task-specific self-efficacy had a role in spatial recall performance after the participants learned a virtual environment. Therefore, after we controlled for other individual factors (i.e., visuospatial abilities, sense of direction, and spatial anxiety), task-specific self-efficacy emerged as a predictor in spatial recall performance after the participants learned a virtual environment (i.e., route retracing and map-completion tasks). These results therefore underline the importance of considering not only global spatial self-efficacy when assessing self-efficacy but also measures of self-efficacy specifically related to the task proposed (Beaudoin & Desrichard, 2011). Indeed, according to Bandura's (1977) self-efficacy theory, one's self-efficacy right before performing a task (or concurrent self-efficacy) influences their cognitive performance by changing the way the person acts, thinks, and feels during task completion.

In addition, Study 2 investigated the relationship between spatial self-efficacy and spatial recall performance after participants learned a virtual environment not only from a correlational point of view but also experimentally through manipulation. We investigated whether receiving feedback on visuospatial abilities (small-scale abilities) would have an effect on the participants' subsequent environment learning and spatial recall performance (large-scale abilities). To address this issue, we gave one group positive normative feedback on their scores in visuospatial tasks, and we gave another group neutral feedback. The results did not show a direct effect of positive normative feedback on spatial recall performance but suggested an indirect effect through task-specific spatial self-efficacy. Therefore, providing a positive evaluation of the performance after the participants completed visuospatial tasks was related to better self-efficacy perceived in subsequent environment learning and, in turn, the latter was related to better performance on spatial recall tasks. The finding that experimentally inducing self-efficacy in some visuospatial tasks may increase task-specific self-efficacy in environment learning and performance supported earlier findings on other domains (e.g., arithmetic tasks; Peifer et al., 2020). However, the result that only an indirect and not a direct relationship emerges could also indicate that different people may react differently to feedback; for some it may have increased their sense of self-efficacy to the point of motivating them to work and commit more to the spatial tasks, while for others it could lead to overconfidence without results in their actual performance.

In addition to environment learning, in Study 3, our focus moved to other important aspects of navigation ability, such as navigation behaviors. While navigating, people may enact behaviors that can facilitate or hamper their learning about an environment (also called navigation behaviors);

indeed, people can show tendencies either to explore an environment or to rely on GPS devices to navigate a new environment (He & Hegarty, 2020). In Study 3, we newly proposed that spatial self-efficacy could be related to navigation behaviors (i.e., exploration tendency and GPS use). The results showed that spatial self-efficacy was positively associated with the tendency to explore an environment and negatively with the tendency to use GPS, suggesting that the more effective and confident people feel while navigating, the more they enjoy exploring their environments and the less they use GPS. This pattern of findings highlights that self-efficacy may play a role in navigation, suggesting that it is associated not only with performance but also with different choices during navigation, such as the tendency to explore or to use a GPS device.

Furthermore, in Study 3 and Study 4, we proposed connections between the self-efficacy theory, the growth mindset theory, and stereotypes within the domain of spatial cognition. Surprisingly, not enough research findings were available on the relationship between different beliefs about spatial abilities. We used a mediation modeling approach and mixed models to investigate whether spatial self-efficacy is related to other beliefs about spatial abilities, such as the growth mindset and gender stereotypes, in predicting navigation behaviors (Study 3) and spatial recall performance after the participants learned a virtual environment (Study 4).

Study 3 investigated the associations between the growth mindset, spatial self-efficacy, and navigation behaviors (i.e., exploration tendency and GPS use). Furthermore, we investigated the associations between gender stereotypes, spatial self-efficacy, and navigation behaviors (i.e., exploration tendency and GPS use). In line with our expectations, the results indicated the growth mindset is associated with self-efficacy in both men and women, showing that those who have higher growth mindsets about their spatial abilities also tend to have higher levels of personal self-efficacy. These findings extend the relationship between self-efficacy and the growth mindset into spatial cognition in addition to other domains (e.g., Chen & Pjares, 2010). Regarding gender stereotypes, we found that they are differently related to self-efficacy in men and women. Indeed, we found that both men and women believe men perform slightly better than women; moreover, endorsing such beliefs is associated with spatial self-efficacy in an opposite way in men and women. In women, the gender stereotype is negatively associated with spatial self-efficacy, and in men, the association is positive. Although we did not find differences between men and women in possessing gender stereotypes regarding spatial abilities and navigation, interestingly, it is slightly shifted in favor of men. In addition, these beliefs would seem likely to have a negative influence on self-efficacy in women (considering this interpretation with caution, given the correlational nature of the study).

Finally, we found a mediational role of spatial self-efficacy between growth mindset and gender stereotype with navigation behaviors (i.e., exploration tendency and GPS use). These results suggest a connection between beliefs about spatial abilities and highlight that a sense of effectiveness and more general beliefs about one's own and others' abilities (growth mindset and gender stereotypes) are related to different behaviors when navigating and learning a new environment (i.e., exploration tendency and GPS use).

In Study 4, we further investigated the relationship between various beliefs about spatial abilities, examining different components of environment learning and spatial knowledge. More specifically, we investigated whether one's self-efficacy right before performing a task could depend on other beliefs about their spatial abilities (i.e., mastery experience, growth mindset, and gender stereotypes) in the relationship with spatial recall performance after the participants learned a virtual environment. When analyzing different tasks after the participants learned an environment, we found that one's task-specific spatial self-efficacy before performing a task interacts with mastery experience and gender stereotypes. In other words, task-specific self-efficacy before a task contributes to their spatial recall performance in location-egocentric and location-allocentric tasks together with their past performance (mastery experience). Therefore, in both location egocentric and location allocentric tasks, task-specific self-efficacy before completing a task not only predicts better performance but also seems to depend on people's evaluations of their previous successes and performances (mastery experience). Finally, in location allocentric performances, task-specific self-efficacy interacts with gender stereotypes. In this case, however, task-specific self-efficacy before one performs a task is associated with a better spatial recall performance in those with lower gender stereotypes in comparison to the opposite sex.

In addition, for this dissertation, we further investigated the role of gender not only in spatial recall performance after the participants learned a virtual environment but also in navigation behaviors (i.e., exploration tendency and GPS use) and beliefs about spatial abilities (i.e., spatial self-efficacy, growth mindset, and gender stereotypes).

Regarding the performance in environmental learning and spatial recall performance, in Study 4, we investigated gender differences considering different components of spatial knowledge, as a recent classification suggested (Claessen & van der Ham, 2017). This classification allows a broad range of spatial knowledge with which to test men and women, considering landmark, location, and path knowledge but also integrating egocentric, route and allocentric, survey perspective taking (Claessen & van der Ham, 2017; van der Ham & Claessen, 2020). Gender differences in survey knowledge of an environment are often reported in the literature and therefore expected (see Coluccia & Louse, 2004, for a review). Our results, however, showed that differences between men and women emerged only in the landmark task. Our results do not seem to be in line with previous research showing women to prefer landmark information when navigating (Sandstrom et al., 1998; Saucier et al., 1999); nevertheless, in our task, the landmarks were shown within the virtual environment (not just the building), making it not only a recognition task but also a spatial recall task asking the participants to remember from what side they saw the landmark relative to the route they previously learned. Overall, our findings on gender differences in spatial recall performances are not in line with studies that have found greater differences in survey-like than route-like abilities (e.g., Castelli et al., 2008). A possible reason could be that the previous studies had a learning phase within the environment in which participants actively navigated the environment, in our study instead (due to the pandemic) people watched a video and thus the task was more passive. A more challenging learning phase might show more differences. More research is needed on gender differences in environment learning and spatial recall performance. For example, a systematic review or meta-analysis that focuses on gender differences by comparing different types of spatial knowledge (e.g., route and survey knowledge) could be useful for clarifying the existence of gender differences in environment learning.

To further investigate the roles of gender, we examined gender differences in navigation behaviors (i.e., exploration tendency and GPS use). The results showed that men and women differ in GPS use and exploration tendency. Indeed, women report more GPS use and less exploration compared to men. Therefore, at least according to our results, not so much spatial recall performance but rather the types of navigation behaviors reported seem to bring out the differences between men and women. However, it should be kept in mind that spatial recall performance was measured with objective tasks, whereas navigation behaviors were self-reported through questionnaires.

Concerning beliefs about spatial ability, we found that men and women differ in spatial self-efficacy and its source (mastery experience) and in growth mindsets. Men report being more effective in environmental and navigational situations (global spatial self-efficacy) and claim to have been more successful in past spatial and navigational situations. Finally, men report believing more in the possibility of enhancing their spatial abilities than women. These results highlight how the subjective reported experience of women in relation to environmental tasks and situations differs from that of men.

Finally, the relationships between gender, self-efficacy, and spatial recall performance were further investigated with a mediational model. In Study 1, we found that self-efficacy (together with visuospatial abilities) mediates the relationship between gender and spatial recall performance (map-completion task). In other words, being a woman is negatively associated with spatial self-efficacy (global and task-specific) and, in turn, spatial self-efficacy is positively associated with spatial recall performance (i.e., map-completion task). Therefore, interestingly, we newly found that rather than gender, lower self-efficacy could negatively relate to spatial recall performance in relying on the ability to create a mental representation (map-completion task).

However, men and women did not differ in self-efficacy reported immediately before and after each spatial learning task (Study 4). Thus, what is remarkable about these findings is that we do not detect differences in performance (except on the landmark task) or task-specific self-efficacy in spatial recall performance but rather in more general beliefs about self-efficacy, the growth mindset, and past spatial successes. Moreover, no differences emerged in gender stereotypes between men and women; however, an interesting observation is that both tend to believe men are better navigators than women are.

Overall, this pattern of results suggests that beliefs about spatial abilities in particular, global spatial self-efficacy, successes in spatial situations, and the growth mindset could differentiate men from women, and spatial self-efficacy can account for gender differences in spatial recall performance.

To conclude, studying spatial performance in men and women is not interesting in itself, but rather how self-efficacy and spatial beliefs differently shape and influence the person in approaching the task allows us to understand different patterns of performance. This research has newly expanded the self-efficacy theory, the growth mindset theory, and stereotypes into the domain of spatial cognition, showing that beliefs about spatial abilities may play a role in people's abilities to learn an environment and may underlie gender differences.

6.2 Limitations and Future Directions

In this section, we present some limitations of our work and issues that are worth considering and that future studies might address. Some limitations exist relative to each study. Among them, one possible limitation of Study 1 consists of how task-specific self-efficacy was measured. In fact, we asked participants only one question to evaluate their self-efficacy before they performed each recall task and after they received instructions for the tasks. There was a chance that the participants may have mentally completed the task during the brief period between when we gave them the instructions and when they responded to the question. If this were the case, the mental simulation of the task would have had an impact on their self-efficacy scores in addition to their self-efficacy esteem. This issue should be taken into consideration in future studies, by giving the participants specific instructions (essential for self-efficacy judgments) and preventing mental simulation (e.g., saying, “You will be asked to imagine being at a certain point of the route and to point to another” instead of saying, “You will be asked to imagine being at the arrival destination and to point to the starting point”).

Another possible limitation may concern the experimental manipulation adopted in Study 2. For ethical reasons, we analyzed only the positive and neutral (not negative) conditions to avoid arousing negative emotions among the participants (e.g., anxiety after negative feedback on their performance). Thereby, the positive feedback might differ from the neutral one in that it provides information with a positive valence. Thus, the latter could create a confounding factor. A difference in the valence within the conditions could make less clear whether any differences detected are related to the feedback itself or to the valence of this information in the feedback. Therefore, the valence associated with feedback could have aroused emotions or feelings in the person that were not controlled in the experiment. The person could have experienced a positive or negative emotion and it would be the latter that could have had an effect on performance rather than an increase in self-efficacy. To disentangle this issue, future studies could provide as neutral feedback the information that the participants performed on an average level in the neutral condition (more positive valence) in comparison to the positive feedback.

Furthermore, to overcome the weak effect of positive feedback in Study 2, future research might also look at feedback that is genuine rather than made up or at input that emphasizes the effort put into the completion of the task rather than an evaluation of the performance. Additionally, feedback delivered by a credible person rather than a computer screen could have a greater influence on performance (Bandura, 1997).

Finally, concerning Study 3, a limitation derives from the use of only self-reported measure. Another weakness is the potential association between the factors the study looked at and other variables. For instance, the frequent use of GPS could be connected to driving (Nori & Piccardi, 2022), which could explain the differences in usage across the participants. Therefore, future studies on navigation behaviors should consider participant driving behaviors in addition to any other factors that might be relevant.

Finally, the studies conducted in this dissertation are cross-sectional and do not allow the formation of conclusions about the causality of the hypothesized relationships. Future experimental studies should look at both causal directions, replicating and complementing previous results, by adopting a longitudinal approach or using different types of experimental manipulation.

6.3 Practical Implications

These results show that for success in environment learning and navigation, multiple individual factors require consideration, including one's own and others' beliefs about spatial abilities. These beliefs could be the subjects of psychoeducational interventions and cognitive training in spatial abilities. In terms of practical implications, these results could provide insights into methods for implementing interventions and training aimed at improving spatial skills (given the suggested beneficial effects of spatial abilities training; Uttal et al., 2013). Cognitive or psychoeducational trainings might also include some sessions in which the theme is beliefs associated with spatial skills. Explaining the importance of self-efficacy in conjunction with the growth mindset and debunking stereotypes (e.g., gender stereotypes) may prove beneficial for enhancing performance. Other points could be providing opportunities for successful performance in order to gain mastery experience and providing knowledge about the importance of one's beliefs and the effectiveness of one's abilities; these steps could be offered to people of all ages. This knowledge could promote self-efficacy and could have a role in men's and women's abilities to acquire and maintain environmental information.

Acting on beliefs could then have spillover into broader areas of life such as the STEM fields. In fact, spatial abilities overall constitute skills that are involved in the STEM fields, and still today, women are underrepresented in these fields. Studying gender differences in spatial abilities and, more importantly, studying factors underlying these differences can help develop the understanding of the underrepresentation of women in these disciplines.

Furthermore, working to abolish gender stereotype threats and improve self-efficacy and growth mindsets in women may further enhance their spatial skills and thus their success in STEM careers.

6.4 Conclusions

To conclude, in this dissertation, we investigated the association between beliefs about spatial abilities and navigation ability (i.e., environment learning and navigation behaviors), showing that people's spatial self-efficacy, growth mindsets, and gender stereotypes about spatial abilities can play a role in men's and women's spatial recall performances and navigation behaviors. In particular, self-efficacy in accomplishing a general spatial situation but especially self-efficacy before performing a specific spatial task seems to predict and sustain the ability to recall spatial information requiring different types of knowledge (route and survey) and perspectives (egocentric and allocentric). Moreover, in line with previous studies on other domains (e.g., Peifer et al., 2020), the experimental manipulation of self-efficacy in core visuospatial abilities seems to indirectly relate to spatial recall performance by enhancing its task-specific self-efficacy. The functional role of spatial self-efficacy emerged consistently in the results of this dissertation, newly suggesting its importance in one's spatial capabilities in the domains of environment learning and navigation behaviors (i.e., exploration tendency and GPS use). These findings clearly extend the self-efficacy theory into the cognitive domains of spatial cognition and environment learning.

In addition to spatial self-efficacy, other beliefs about spatial abilities were examined to better understand the mechanisms underlying individual and gender differences in spatial recall performance after the participants learned a virtual environment. Our results clarify that an individual's spatial self-efficacy can relate to their beliefs in the possibility of improving personal spatial abilities (growth mindset), to previous successes in spatial situations (mastery experience), and to their beliefs that men and women differ in spatial abilities (gender stereotypes). However, while men and women thinking in the possibility to improve their spatial ability and referring successful spatial situations in the past reported also higher spatial self-efficacy, in women, the gender stereotype may have a detrimental effect on their self-efficacy beliefs. Indeed, women endorsing the belief that men are better in environment learning illustrates their lower self-efficacy in environment learning. These studies, therefore, demonstrate the involvement of spatial self-efficacy in the processes underlying the growth mindset and stereotype effects on spatial recall performance and navigation behaviors.

As for the role of gender, we studied the differences between men and women by using different spatial recall tasks to analyze a broad range of components of environment learning according to the work of Claessen and van der Ham (2017). We found that men outperformed women only on the landmark task, and this result is not in line with the previous evidence showing that women prefer to rely on landmarks when navigating and learning an environment (Sandstrom et al., 1998) and showing that women perform worse on survey tasks (e.g., Castelli et al., 2008). This difference could be due to the type of task used in the present study (passive learning and recall) and the previous ones (active learning and recall). Therefore, future studies are needed to clarify the role of gender in different components of environment learning considering a comprehensive analysis of spatial knowledge and taking into account not only landmark, route, and path knowledge but also survey (allocentric) and route (egocentric) perspective taking (Claessen & van der Ham, 2017; van der Ham et al., 2020).

Moreover, we newly found that men report higher spatial self-efficacy, endorse beliefs in the possibility of improving their spatial abilities (growth mindset), and report higher successes in spatial tasks (mastery experience) than women. Both men and women believe that men perform slightly better in environment learning and navigation ability. Furthermore, our results demonstrate the mediating role of spatial self-efficacy between gender and spatial recall performance, suggesting personal beliefs about self-efficacy could underlie gender differences in spatial recall performance after participants learned a virtual environment. Taken together, these results suggest that subjective evaluations of personal spatial abilities are different in men and women and that such differences could explain the possible gaps in spatial recall performance and navigation behaviors between men and women. Understanding the role of individual differences in environment learning and the relationship with beliefs about spatial abilities could be important for application purposes, such as the design of person-centered training.

In conclusion, this research offers some insights to enlarge the theoretical framework with empirical evidence of the study of individual factors involved in navigation ability, a central issue in spatial cognition. At the same time, new evidence is offered, increasing the complexity of the matter due to the interaction of multiple individual factors.

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