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Spatial Navigation and Negative Emotions
The Effect of Emotion Processing on Wayfinding and Visuospatial Working Memory

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ABSTRACT

Travelling unfamiliar environments is an essential ability. When navigating, we are exposed to a vast amount of information, but some cues might be more relevant than others. While there is a well-established understanding of mechanisms underlying orientational skills and a wide consensus on the effect of facial emotional processing on most cognitive processes, little is known about the interplay between processing others' emotions and spatial navigation abilities. The present research consists of five experiments with approximately 1,000 participants to investigate how processing other's negative emotions influences wayfinding, spatial navigation domains, and visuospatial skills. Gender differences were considered in all experiments. In Experiment 1, participants navigated three virtual environments twice. The first time was to find an object, and the second time was to recall the path to reach it. Between the two phases, participants performed a gender categorisation task of faces showing neutral, fearful, or angry expressions. Results showed that exposure to fearful faces, but not angry or neutral faces, impaired males' navigation performance, whereas females were unaffected. In Experiments 2 and 3 we extended this research to different emotional stimuli (i.e. bodies or contexts) and found no significant impact on wayfinding. In Experiment 4, we further explored how facial negative emotions affect navigation domains with six tasks, showing that processing fearful faces (and to a lesser extent angry faces) impaired males' and enhanced females' performance, but only in tasks involving location strategies and path survey knowledge. Experiment 5 extended the research to visuospatial skills, which are essential for navigation and face processing. The study evaluated whether processing negative emotions during a visuospatial task (Delayed Non-Match to Sample Task, DNMS) affects performance on a subsequent visuospatial task (Backward Corsi Block Tapping Task, CBT). The results showed that participants' performance in the DNMS task decreased with fearful faces (compared to angry or neutral faces). However, only male participants showed a decrease in performance in the following CBT, which might be due to gender differences in cognitive load management. This dissertation highlights the link between emotion processing and navigation, suggesting face, emotion, and gender-specific effects, and provides direction for future research.

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CHAPTER 1

THEORETICAL BACKGROUND

1.1 GENERAL INTRODUCTION

Spatial navigation and emotion processing are complex phenomena that significantly influence human behaviour and cognitive functioning. Spatial navigation refers to the ability to locate oneself in space and traverse physical environments (O'Keefe & Nadel, 1978; Brodbeck & Tanninen, 2012). Wayfinding, on the other hand, refers to successfully identifying a destination and creating a route to reach it, embodying the strategic and purposeful component of navigation (Lynch, 1960; Farr, 2012). Conversely, emotions are subjective experiences characterised by feelings, thoughts, and physiological responses that play a central role in shaping behaviour, decision-making and social interactions (Ekman, 1992). Despite the growing number of studies investigating spatial navigation and orienteering (Burgess, 2008; Wolbers, 2015; Epstein, 2017; Ekstrom et al. 2018), there is limited knowledge about the impact of processing negative emotional information on these dynamics. Specifically, research on the effect of perceiving and processing emotional stimuli on basic cognitive functions has overlooked the impact of processing others' emotional expressions (i.e., fear vs. anger) on wayfinding and spatial navigational mechanisms (Pessoa, 2012; Zhao et al., 2024; Ruotolo et al., 2018). When navigating unfamiliar environments, the challenge of avoiding disorientation becomes paramount, particularly amidst the myriad of cues demanding attention, memory, and decision-making (Lichtenstein et al., 2012). Spatial navigation, though often selective and adaptive, can still be disrupted by distractions or unexpected stimuli. For instance, imagine walking down a poorly lit street at night, and encountering potentially threatening individuals. Here, one must balance choosing a path while distracted by the circumstances or concentrating on remembering the route to avert danger. Similarly, in a scenario like a fire alarm in an office, amidst obscured landmarks and palpable fear, it's crucial to remain calm and follow the designated evacuation route, rather than succumbing to instinct or crowd behaviour. Such decisions become pivotal in uncertain circumstances, where impulsive reactions may compromise safety.

Successful navigation can emerge by adopting adaptive behaviours influenced by primal fight-or-flight responses to stimuli (Ekman, 1993; Dalgleish, 2000), despite uncertainty (Tenbrink, 2020). Nonetheless, emotions and their consolidated effects on most cognitive functions, so deeply ingrained evolutionarily, psychologically, and socially, might shape navigational outcomes as well. In threatening or even ordinary situations, other people's facial expressions convey information about the unfolding events around one person and ultimately determine the proportion of resources devoted to threat detection and optimal navigation. For example, while a navigation task is in progress, observing the emotional reactions of strangers, such as fear or anger, could affect their performance.Hence, observing the emotional reactions of strangers such as fear or anger while a navigation task is in progress could influence its performance. Hereby, our primary aim was to investigate whether processing others' negative emotional expressions affects spatial navigation abilities. In doing so, we also took into account gender differences which are key in both emotion perception and navigation. Throughout five experiments we investigated whether negative expressions could affect not only behavioural outcomes during realistic and immersive wayfinding in VR, but also their impact on the underlying cognitive domains of spatial navigation. Eventually, we assessed whether a conflict for the underlying visuospatial resources might be in place when performing a visuospatial task while processing facial emotions.

The following dissertation is structured as follows: In the first chapter, we review and summarise the current literature on spatial navigation and emotion processing, highlighting gaps and open questions that lead to our research questions.

In the second chapter (*Experiment 1*), we report how negative facial expressions (i.e., fear vs. anger) affect spatial navigation in a virtual reality environment. Additionally, we conducted two experiments to determine whether the observed effect was solely due to facial expressions or whether body expressions without the facial component (i.e. blurred faces*; Experiment 2*) or emotionally relevant scenarios without human elements (*Experiment 3*) could also influence wayfinding. In the third chapter, we investigated the influence of emotional face processing on spatial navigation cognitive domains (*Experiment 4*). In the fourth chapter, we extend our findings to visuospatial cognitive factors that are behind spatial navigation and might compete for the same resources used by facial emotion processing. This may explain our findings and clarify how emotional face processing affects visuospatial abilities necessary for navigation (*Experiment 5*). In the fifth and final chapter, we discuss our results and how they might answer our open questions, highlighting the limitations, and providing future directions on the interplay between gender, emotion and navigation.

1.2 DYNAMICS OF SPATIAL NAVIGATION

1.2.1 Spatial Navigation: Wayfinding, Locomotion and Orientation

Spatial navigation is the process by which organisms use multiple cue sources such as cues, landmarks, and beacons to determine the route to a goal and then travel that route (Brodbeck & Tanninen, 2012). Spatial navigation is concerned with actual navigation or wayfinding in physical environments and focuses on the practical use of spatial information for movement and interaction in the environment. It involves finding a path, mapping a route, and orienting oneself in a real-world environment to reach a destination. Efficient navigation allows us to perform various tasks being a common skill that we use every day, whether navigating small-scale environments such as homes and workplaces, or larger-scale environments such as cities (O'Keefe & Dostoevsky, 1971; Burgess, 2008; Golledge, 1999). In a nutshell, it is the practical application of spatial knowledge to effectively move from one place to another (Epstein et al., 2017).

One of the first analyses of human spatial learning was done by Trowbridge C.C. in 1913. He studied the use of "imaginary maps" in human orientation tasks. Then, in 1948, Edward Tolman coined the term "*cognitive map*" to refer to the internal mental images of physical spaces that animals and humans use to navigate the real world, especially to discover new shortcuts. Tolman's theory suggests that memories of recently travelled paths merge with memories of previously explored paths, reinforcing the notion that spatial cognition goes beyond basic stimulus-response associations. Rather, it involves accessing spatial knowledge throughout the environment and using these maps to plan future trajectories (Tolman, 1948; O'Keefe & Nadel, 1978). Spatial navigation, indeed, can be divided into two main skills that are practically inseparable but conceptually independent (Dalton, Hölscher & Montello, 2019): *locomotion and wayfinding* (Wolbers, 2015; van der Ham, 2020).

Locomotion, the real-time aspect of navigation, requires the skilled execution of movement in the desired direction while avoiding collisions or obstacles. It involves coordination within the immediate sensory and motor environment to meet the demands of the moment It requires overcoming challenges such as identifying stable surfaces, avoiding obstacles, and steering towards recognisable landmarks (Wolbers, 2015; van der Ham, 2020).

Wayfinding, on the other hand, is a term coined by Kevin Lynch in 1960 referring to identifying a destination and creating a route to reach it, embodying the strategic and purposeful component of navigation, for this reason, 'navigation' is often used interchangeably with 'wayfinding'. Yet, it can be defined as a purposeful act involving decision-making and problem-solving to primarily reach a fixed destination (Allen, 1999; O'Neill, 1992) often beyond the immediate vicinity of the traveller. It involves a set of procedures such as orientation, route selection, route monitoring, and destination recognition. These procedures allow individuals to estimate directions, reach their destinations, learn their positions, and recall locations (Farr, 2012; Montello & Raubal, 2013). Consequently, they encapsulate individuals' schemas and decision-making processes for efficient navigation, which are highly dependent on the context and complexity of the environment (Siegel & White, 1975; Thorndyke & Hayes-Roth, 1982). Accordingly, while locomotion describes the coordination required to move around our bodies without interruption, wayfinding is about planning, deciding, acting, and monitoring our way to a destination. It depends on both environmental and self-motion cues, as well as the body, spatial references, and knowledge-based strategies (Do et al., 2021; van der Ham, 2020; Montello & Raubal, 2013; Siegel & White, 1975; Sjolund et al., 2018; Tolman, 1948; O'Keefe & Nadel, 1978).

Finally, to maintain so-called *'orientation'* while moving, individuals rely on a combination of two processes: *landmark-based updating* and *dead reckoning or path integration* (Fernandez et al., 2019). *Landmark-based updating* involves the recognition of specific features or locations in the environment, drawing on either internal or external memory. Another aspect of spatial navigation involves landmarks. Although external sensing of these landmarks is required, navigators do not need to process information about their movement (Bécu et al., 2023). Interestingly, *object-location memory*, is a specific memory for fixed object locations, relating the encoding of categorical and coordinate position information and the linking of object and spatial information. Spatial representations in this case can be divided into two types: coordinate and categorical (i.e., with or without precise metric measurements). The left cerebral hemisphere is specialised for categorical spatial representations and the right cerebral hemisphere is specialised for coordinate spatial representations (Kosslyn et al., 1989; Laeng, 2013; Jager & Postma, 2003).

Path integration, instead, monitors locomotion-related components such as velocity, acceleration, and travel time. This process continuously updates one's position and orientation based on self-motion cues, helping to maintain a sense of place in unfamiliar environments. Path integration is a process by which navigators estimate their position and orientation relative to a known location using body-related internal sensory cues. These cues are derived from navigation-related body movements, such as vestibular and proprioceptive signals. While humans are capable of path integration in small spaces, its role in large-scale navigation has been questioned due to its inherent susceptibility to error accumulation. Research suggests that navigation with path integration (e.g. walking in a large environment) can enhance learning of the layout of the environment compared to mere exposure without path integration (e.g. watching a walking video while seated). This hints that body-based cues are reliably processed and encoded by path integration during navigation. The effect is more pronounced when proprioceptive cues (related to body movement) are available compared to vestibular cues alone (e.g. driving or being pushed in a wheelchair). Path integration with proprioceptive cues can help build survey knowledge of the environment, where metric distances and directions between landmarks are represented (Anastasiou et al., 2023). Understanding how creatures navigate and orient themselves in their environment has been an essential part of early experimental psychology. Nowadays, researchers are investigating path learning and recall using virtual environments (VEs) that serve as good approximations of real environments, in which humans can acquire spatial information through both active and passive navigation (Muffato et al., 2023).

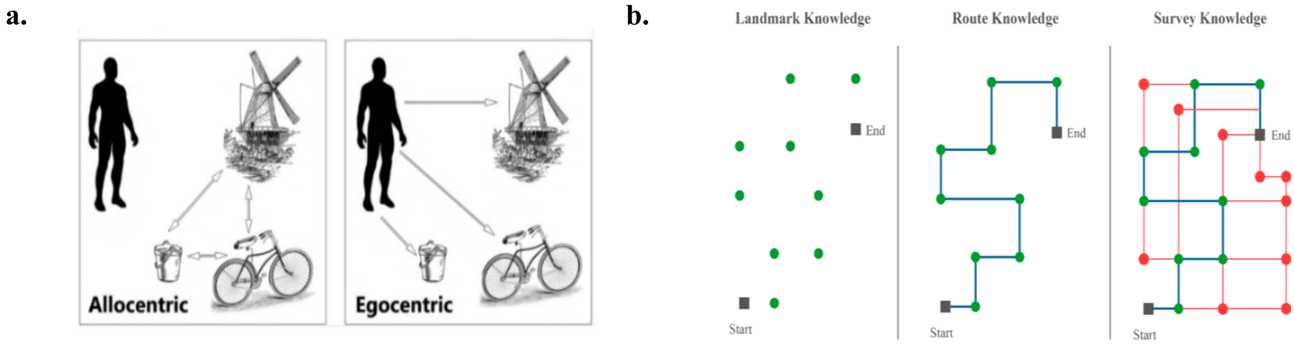
Most research in spatial navigation has attempted to identify the components that make up an individual's spatial knowledge as a basis for effective navigation in the environment. Siegel and White (1975) proposed a model of *spatial knowledge acquisition* based on three stages: *landmark, route, and survey* (Figure 1.1 b). In the first stage, the process is limited to the landmarks available in an unfamiliar environment. In the second stage, information about the connecting routes between the landmarks is encoded. This is initially done by a non-metric representation, which is later extended to include metrics such as distances, durations and angular deviations. Thirdly, the observer can use a map with an allocentric viewpoint to survey the area. A more recent version by van der Ham (2020) proposed an updated subdivision. The *domains of navigation* were named*: landmarks, places, and paths,* reflecting a tripartite structure of spatial knowledge that also reflects the historically relevant directions of research in the field. Importantly, each domain can be conceptually independent but loaded by a single latent factor that accounts for an individual's spatial knowledge (Muffato et al., 2023).

The *landmark domain* involves the identification of unique features or objects in the environment that act as reference points, helping to make decisions about direction and location and answering the *'what'* question. Landmarks can help with orientation. However, it only provides information about the location of a new point in relation to a previously visited point and is prone to accumulating errors if not periodically corrected by landmark-based processes.

The *location domain*, on the other hand, includes places that can be visited or imagined, and the routes that connect them. They are the most direct way of moving from one place to another and are often used to navigate between landmarks. It refers to specific ways of moving from one place to another, drawing on procedural and declarative knowledge. It addresses the question of "*where*" and focuses on understanding spatial positions within an environment. Location knowledge fits well with the common distinction between *egocentric and allocentric referencing* (Klatzky, 1998). A particular location can be coded as either 'to my left' (egocentric) or 'north of the town hall' (allocentric) (see Figure 1.1.b). *Egocentric location* involves directional information from the observer's current or past position in the environment, involving an observer-based or first-person perspective, and is primarily associated with activation in parietal cortex (Tlauka & Wilson, 1994). *Allocentric location*, in contrast, uses an environment-based perspective that ignores the observer's current position and is associated with hippocampal activation. Therefore, allocentric location knowledge can be expressed in terms of the location of relative elements in the environment, independent of the observer's previous interaction with the environment (Kuipers, 1978).

The *path domain*, finally, represents the most complex aspect and addresses the question of *'how to get there'*. It encompasses the spatial relationships of a given landmark and reflects how the location of the landmark relates to other elements in the environment (van der Ham, 2020). The often-quoted distinction between route and survey knowledge is applicable here: *Route path* knowledge concerns a specific route one can take to reach a given location and depends primarily on the spatial context of landmarks and their relationships to our position in the environment. *Survey path* knowledge, on the other hand, allows us to represent a spatial configuration from a bird's eye view and to form cognitive maps of the environment (Lynch, 1960; Rand, 1969; Siegel & White, 1975). The latter is independent of our position and allows us to find shortcuts, detours and even entirely new routes to our destination (O'Keefe & Nadel, 1978; Tolman, 1948). It also includes estimated distances between landmarks, as they might appear on survey maps. It can be represented imaginatively or propositionally, as in numerical distances (Montello, 1998). In summary, the acquisition of cognitive maps is a gradual construction involving multimodal knowledge integrated step by step from diverse sources, and to obtain meaningful objective measures of navigational performance, each of these three navigational domains must be assessed (van der Ham, 2020).

Figure 1.1 (a.) Spatial Coding Systems Adapted from Klatzky, 1998, Spatial Cognition, and **(b)** Landmark-Route-Survey Knowledge by Siegel & White, 1975 retrieved from Advances in Child Development and Behaviour.



1.2.2 Cognitive Functions Employed in Spatial Navigation

The mechanisms identified in the field of spatial navigation span through different domains and collectively support a wide range of cognitive functions (Bellmund et al., 2018). Spatial navigation is an intricate cognitive apparatus that relies on a variety of cognitive abilities, including attention, perception, memory, visuospatial memory, executive function, decision-making, and problem-solving (Faedda et al., 2022). In the following section, we will discuss the specific cognitive functions involved in spatial navigation in order to gain a better understanding of their role.

While complete or highly accurate geographic orientation is not always necessary, a rudimentary and partial understanding is often sufficient for efficient wayfinding, this highlights the importance of having sufficient knowledge to reach one's destination. Equally important is the awareness of possessing this knowledge, as uncertainty about location or direction can elicit negative emotional responses during wayfinding, leading to geographic disorientation and potential loss of way (Hill, 2019).

Attention is clearly the cornerstone for perceiving and selecting relevant environmental information. *Spatial attention*, in particular, it is the cognitive process of selectively focusing on certain locations in the visual field while ignoring others (Luck, et al., 1989) allowing to process cues such as landmarks and directional signs that are critical for effective navigation (Parasuraman, 1998). It has two main components: *selective attention* that allows individuals to focus on a particular location or stimulus, filtering out irrelevant or less important information (Luck et al., 1997); and *spatial orienting* that involves the voluntary or involuntary shifting of attention from one location to another (Posner, 1980). The latter can be triggered by salient or novel stimuli (bottom-up processes) or influenced by individual goals and expectations (top-down) (Corbetta & Shulman, 2002). This information may be stored internally as cognitive maps within the traveller's cognition, or externally through information displays. Accessibility and processing of this information must be contextually appropriate, avoiding overwhelming amounts of data that may divert attention from relevant information and hinder the wayfinding process. The form and mode of information also has a significant impact on the success of wayfinding (Brown & Chrastil, 2019).

Along with attention, there is also *perception, which* includes encoding and interpretation of (multi)sensory stimuli for the construction of mental representations (Golledge, 1999). The interpretation of sensory input contributes to determine one's location, orientation, and direction of movement (Wiener, 2018). It promotes spatial awareness by allowing individuals to recognise landmarks, paths, and obstacles, and assists in the construction of mental maps (Passini, 1984). Indeed, through visual perception of landmarks, individuals receive proprioceptive feedback to determine their orientation relative to their surroundings (Riecke et al., 2017).

One fundamental aspect of this integration is *perceptual integration*, where disparate cues are combined to form a unified understanding of our surroundings (Hogben & di Lollo, 1974). This integrated perceptual function serves multiple purposes, including aiding survival, facilitating object recognition, and enabling interaction with the environment (O'Hare, 1991). By seamlessly integrating various perceptual cues, our brain constructs a rich and coherent representation of the world around us, demonstrating remarkable feats of neural integration (Loomis et al., 1992). Indeed, *perceptual integration* of spatial information includes spatial orientation, visual closure, distance estimation between locations using depth perception, shape perception and motion parallax (Loomis et al., 1992; Postma & van der Ham, 2016).

Spatial orientation, as previously mentioned, is crucial for comprehending our position and orientation in space (Loomis et al., 1992). It involves synthesizing information from multiple sensory inputs, including vision, vestibular signals, and proprioception. This ability allows us to maintain balance, navigate environments, and understand spatial relationships even when blindfolded. Similarly, visual closure enables us to recognize objects or patterns despite missing information (O'Hare, 1991). Our brain adeptly fills in the gaps using prior knowledge and experience. For example, we can identify a partially obscured letter in a word based on its context and our familiarity with the alphabet. Depth perception, another critical component, relies on various visual cues such as binocular disparity and monocular cues (Loomis et al., 1992). This ability allows us to estimate distances between objects accurately, whether it's gauging the depth of a tree in a forest or the distance to a mountain peak. *Shape perception* involves the interpretation of 2D visual inputs to construct a 3D representation of objects (Postma & van der Ham, 2016). Gestalt principles guide this process, aiding in organizing visual elements into meaningful wholes. Even when presented with incomplete information, our brain fills in the missing details to perceive coherent shapes. *Motion parallax* further enhances our perception of depth and relative distances as we move (Fahrenfort et al., 2017). This phenomenon, observed when objects appear to move at different rates based on their distance from us, aids in estimating spatial relationships. For instance, when observing scenery from a moving vehicle, nearby objects seem to pass by rapidly compared to distant ones. In *holistic perception*, these individual processes synergize to provide a comprehensive understanding of our environment (Postma & van der Ham, 2016). For instance, when observing a tree in a forest, spatial orientation informs us of our position, depth perception helps gauge the tree's distance, and shape perception allows us to recognize its form.

Visuospatial perception in particular guides route planning and execution by helping individuals identify potential paths and evaluate route options based on spatial relationships (Montello, 2005). Furthermore, it facilitates spatial updating by integrating new sensory information into existing cognitive maps (Wolbers & Wiener, 2014). Wayfinding strategies are similarly influenced by perceptual cues, with individuals choosing strategies based on environmental features (Soh & Smith-Jackson, 2004). Indeed, visuospatial skills, allow us to navigate our environment, perceive objects and understand spatial relationships, and can be divided into three distinct categories: Spatial visualisation, which involves mentally manipulating complex spatial information to complete tasks that require multiple steps. For example, arranging items to fit into a suitcase would require spatial visualisation skills. *Spatial perception*, which allows us to accurately establish spatial relationships in the face of distraction, helping us to maintain our orientation even when there's additional information in our environment. Finally, *mental rotation* refers to our ability to mentally rotate objects or images in our mind. It is essential for tasks such as recognising objects from different angles or understanding spatial transformations (de Bruin et al., 2016). *Perspective taking* is another component that coherently allows for transformations from the individual's point of view, imagining the perspective of an object from a different spatial location. These skills show significant individual differences and are strongly associated with performance in tasks involving path recall during navigation (Meneghetti et al., 2021). Assessment of spatial and visuospatial abilities typically involves tasks such as mental rotation of shapes, maze solving and figure finding, which require perceptual inspection or mental manipulation of small objects (Waller, 2001; Garden, 2002; Hegarty et al., 2006).

Spatial learning and spatial memory are also enhanced by perception, as sensory input is encoded into cognitive representations of the environment through repeated exposure (Mou et al., 2006; Conrad, 2010). For an efficient navigation, people might also learn critical details of the surroundings and of the route to a destination. *Spatial learning* involves understanding the layout of the environment and the spatial relationships between different landmarks or locations. *Route learning*, on the other hand, involves acquiring knowledge of specific paths or routes to navigate from one place to another within the environment, memorising specific sequences of actions, turns, roads and landmarks. Success in this endeavour requires the possession of accurate and relevant information about the environment (Wolbers & Wiener, 2014).

An influential theory in the study of spatial learning is the cognitive map theory proposed by Tolman (1948). Tolman conducted studies with rats that suggested they had mental representations of a maze, even though they received no immediate reward for navigating it. In a classic experiment, he divided the rats into three groups. The rats in the first group were taught to navigate the maze and were rewarded with food when they successfully reached the end from the starting point. Over time, these rats learned to navigate the maze correctly by avoiding wrong turns and dead ends. The second group of rats were introduced to the same maze but received no reinforcement for reaching the end. Although they improved over time, they made more mistakes than the reinforced group. The results were as expected, as the group who were rewarded for their efforts were more motivated to learn. The third group of rats completed ten days of learning trials without any reward. On the eleventh day, food was placed at the end of the maze for the first time. Surprisingly, the rats' learning improved significantly with just one reinforcement, and they successfully navigated the maze with the same efficiency as the rats in the first group. This showed that the rats not only made basic stimulus-response connections, but also had a cognitive understanding of the spatial structure of the maze.

Tolman's theory suggests that memories of recently travelled paths merge with memories of previously explored paths, reinforcing the notion that spatial cognition goes beyond basic stimulus-response associations. Rather, it involves accessing spatial knowledge throughout the environment and using these maps to plan future trajectories (Tolman, 1948; O'Keefe & Nadel, 1978). Such an ability to form cognitive maps is essential for navigating in space. This ability depends not only on our movements and the cues in our environment (Brown & Chrastil, 2019; Brodbeck & Tanninen, 2012; Byrne, 2017), but also on creating spatial schemas from our direct experience (Golledge, 2005) or inferring them from the connections between established routes (Byrne, 2017). They provide details about how the environment is laid out, where landmarks are located, the distances between different locations, and how different elements in the area relate to each other. Such details allow people to imagine and understand the space around them, facilitating their ability to navigate and make choices (Wagner, 2006).

Indeed, spatial navigation relies heavily on *memory* to recall important landmarks, paths and locations (Golledge, 1999). This involves a specific type of memory called *spatial memory*, where both *short-term and long-term memory* are used for immediate navigation and for recalling routes and spatial relationships over time (Nadel & Hardt, 2004; Postma, 2005). Specifically, *spatial working memory* allows encoding of the surrounding space, holding and manipulating information in real time during cognitive processing, and contributes to tasks such as commuting or locating personal items (Baddeley, 2002). *Visuospatial working memory (VSWM)* on the other hand plays a crucial role in retrieving and manipulating mental images, maintaining spatial orientation, and tracking moving objects (Logie, 1995; Baddeley & Hitch, 1974).

In other words, visuospatial processing involves the identification, integration, and analysis of visual information in more than one dimension, and serves as a cornerstone for understanding spatial relationships, recognising patterns, and interpreting complex visual scenes (Kosslyn, 1989; Vandenberg & Kuse, 1978). This central skill for our interaction and understanding of the world ranges from basic tasks such as shape recognition to complex endeavours such as navigating intricate environments (Montello, 2005; Garden, 2002). In particular, VSWM is embedded in various aspects of spatial navigation behaviour, including learning from maps, binding object locations, and route memorisation (Muffato et al., 2016, 2019a,b). It acts as a cognitive sketchpad for visual information (Baddeley, 1986; Logie, 2011) and becomes indispensable for movement coordination, depth perception, distance judgement, and spatial navigation (Hegarty & Waller, 2004; Hegarty & Montello, 2006; Kozhevnikov et al., 2006). Whether it is driving a car, reading a map, or appreciating art, our visuospatial skills shape our perception and interaction with the visual world. Impairments in these skills can lead to challenges such as misjudging distances while driving or having difficulty navigating unfamiliar environments (Waller, 2001; Montello, 2005). A reach-and-grasp task has been used to assess visuospatial abilities in adulthood (the Block Tapping Task; Corsi, 1971). In this task, participants reproduce complex models by locating and retrieving building blocks from an array. The time required to complete the task increased mental rotation complexity, and patterns of hand use were influenced by model complexity as well (de Bruin et al., 2016; Mitolo et al., 2015). Coherently, larger spatial tasks place greater demands on visuospatial resources (Waller, 2001; Garden, 2002). Finally, in a meta-analysis using a factor analytic approach, Meneghetti et al. (2021) found evidence of a relationship between improved recall accuracy and individual dispositions and cognitive abilities related to spatial navigation. Thus, whether investigating developmental differences, age-sex-related variations, or pathology-related changes, the assessment of spatial abilities remains a valuable area of research (de Bruin et al., 2016), and understanding these abilities and how they interact is essential for adapting to our environment.

Executive functions, lastly, facilitate the continuous updating of spatial information, adaptation to changing conditions, and maintenance of cognitive control throughout the navigation process (Brown & Chrastil, 2019). Central to these functions is the role of working memory, which allows individuals to temporarily store and manipulate information critical for maintaining and updating spatial information (Baddeley, 2003; Cheng et al., 2002). Fundamentally, executive functions involve also *decision making and problem solving,* and act as a cognitive compass to guide individuals in making informed decisions and adapting to unexpected obstacles. *Decision making* involves evaluating options, making directional choices, and determining the optimal course of action (Golledge, 1999; Wiener et al., 2009). Thus, effective decision making for navigation relies on robust visuospatial skills that allow individuals to assess spatial relationships and choose routes that match their goals and preferences. *Problem-solving skills,* on the other hand, are essential for overcoming challenges encountered during navigation, allowing individuals to find alternative routes and reorient themselves in moments of disorientation (Rosenbaum et al., 2016). They allow individuals to adapt to unforeseen circumstances, find alternative routes and efficiently reorient themselves in moments of disorientation. This adaptive capacity contributes significantly to the effectiveness of spatial navigation in diverse environments. Both abilities show variation between individuals (Brugger 1999; Clayton et al., 2017; Montello, 2007). In the context of navigation, *planning,* sets goals, creates sequences of actions, and considers the potential outcomes of different choices. It helps to develop mental maps and strategies for efficient navigation (Spiers & Maguire, 2006).

Cognitive flexibility, another facet of executive function, allows individuals to adapt to changing circumstances and switch seamlessly between different cognitive tasks or strategies. This involves changing routes or strategies in response to unexpected obstacles or environmental changes (Latini-Corazzini et al., 2010). *Inhibitory control*, on the other hand, is essential for suppressing irrelevant or distracting information, helping to filter out irrelevant landmarks or distractions during spatial navigation and preventing errors (Muffato et al., 2019).

Last but not least, *motivation* is the force that shapes our spatial navigation and wayfinding abilities and is intricately woven into the fabric of our interactions with the environment. It drives us towards specific goals, whether it is reaching a destination, securing resources or avoiding potential hazards (Tolman, 1948). This drive influences every aspect of our navigation, from the routes we choose to the effort we expend and the perseverance we show in the face of obstacles. At the heart of this motivational mechanism is the brain's reward system, with key players such as the ventral tegmental area and nucleus accumbens (Berridge & Kringelbach, 2015). Successful navigation, such as finding food or shelter, triggers the release of dopamine, reinforcing the behaviour and encouraging repetition. Conversely, negative experiences, such as getting lost or encountering obstacles, can dampen motivation and alter our navigation strategies, shaping the mental maps we construct of our environment. The allocation of effort during navigation is another facet influenced by motivation. In situations of high motivation, such as searching for water in a desert, we may exhibit increased exploration, persistence, and risk-taking behaviour (Clark et al., 2012). When motivation is low, our navigational efforts may be less thorough and exhaustive. Interestingly, emotional states, ranging from fear to curiosity to hunger, have profound effects on motivation during navigation. Fear, for example, can enhance spatial memory and facilitate the recall of escape routes, while curiosity drives exploration (Jacobs & Nadel, 1998; Golledge, 1999). Indeed, goals, task relevance, and context dependency are essential to properly study these functions and their behavioural consequences.

1.2.3 Gender differences in Spatial Navigation

Research has identified various components and cognitive factors required for effective navigation; however, individual differences are paramount in this area and gender differences are one of the most obvious (Fischer et al., 2018; Olderbak et al., 2019; Munion et al., 2019). The literature suggests that gender differences in spatial navigation are influenced by a combination of environmental, biological and cognitive factors, to be intertwined with the impact of task complexity and stimulus type on spatial performance (Rilea, 2008). A first possible biological factor contributing to gender differences in spatial navigation is right hemisphere dominance and higher levels of the hormone testosterone in men (Driscoll et al., 2005; Perssons et al., 2013). Research suggests that males often show right lateralised activation in the hippocampus during navigation tasks, which significantly contributes to their performance in distance estimation (Persson, 2013). In comparison, studies suggest that women may rely more on bilateral hippocampal activation during navigation tasks (Grön et al., 2000). This bilateral pattern of activation may reflect a more integrated approach to processing, with both hemispheres contributing equally to spatial cognition. In addition, some research suggests that oestrogen, a hormone more prevalent in females, may influence spatial abilities by modulating synaptic plasticity and neuronal function in brain regions involved in navigation, such as the hippocampus (Luine & Frankfurt, 2013).

Environmental and social factors, on the other hand, play an important role in shaping gender differences in spatial navigation skills. For example, the amount of time spent playing video games with a strong spatial component, such as construction games, has been shown to influence spatial skills (Baenninger & Newcombe, 1989). In addition, opportunities to explore new environments can have a profound effect. In some cultural settings, boys may be given more opportunities to explore new environments than girls (Webley, 1981). A combination of these environmental factors may exacerbate gender differences in spatial and navigational skills (Casey, 1996). For example, boys who spend more time playing spatially demanding video games and have more opportunities to explore may develop stronger spatial skills than girls who have fewer such experiences. Furthermore, spatial anxiety, which refers to negative emotions specific to spatial contexts, has been found to differ between genders (Coluccia & Louse, 2004; Lyons et al., 2018; Malanchini et al., 2017), which is different from a general sense of anxiety (Alvarez-Vargas et al., 2020; McKheen, 2011; Walkowiak et al., 2015). Research suggests that females tend to experience higher levels of spatial anxiety than males (Lawton, 1994). This gender difference in spatial anxiety may also contribute to differences in spatial performance between males and females, further emphasising the multifaceted nature of gender differences in spatial navigation skills.

Recent meta-analyses have consistently found a male advantage in numerous spatial tasks (Voyer & Saint-Aubin, 2017; Voyer, Postma & Brake, 2007). Males often show superior performance on these types of tasks compared to females (Halpern, 1996). As highlighted above, navigation relies heavily on memory. Some recent studies suggest that working memory (WM) load may also contribute to differences in orienting abilities (Voyer & Saint-Aubin, 2017). According to Garden, Cornoldi, and Logie (2002), the memory load implied by the wayfinding process is not a general cognitive load, but explicitly belongs to visuospatial working memory (VSWM) (Coluccia & Louse, 2004). One might therefore expect that gender differences in VSWM would also account for differences in spatial cognition and navigation.

Although it appears that males outperform females in keeping track of their original location, with higher scores in tasks involving VSWM, fluid reasoning, positional reconstruction and spatiotemporal analysis (Gonzalez-Garrido et al., 2015), females excel in episodic and semantic memory tasks, verbal, analytical working memory and object location memory. Interestingly, their advantage is only attenuated when the task requires visuospatial processing (Persson et al., 2013; Lewin et al., 2001). Furthermore, Bowers (1988) suggested that high-ability females and low-ability males may use a verbal mediation strategy when processing spatial visualisation tasks, while Kim and colleagues (2007) observed that females responded faster in 2D matrix navigation tasks with landmark instructions, while males were more accurate in recognising key elements in driving scenes.

One of the major differences between the genders also lies in the cognitive navigation strategies employed (Saucier et al., 2002). Research suggests that females tend to prioritise landmark information, demonstrating a tendency towards procedural 'route-based strategies' (Pazzaglia & De Beni, 2001). In contrast, males often prioritise geometric information, using a more efficient "survey strategy" that involves maintaining a sense of position with cardinal points, such as north, or distances, such as 100 metres (Sandstrom, Kaufman & Huttel, 1998). With regard to the domains of egocentric and allocentric location knowledge and survey path knowledge, it is suggested that they require a significant amount of geometric processing, potentially leading to a male advantage (van der Ham et al., 2020). Conversely, landmark knowledge and route-path knowledge rely heavily on landmark processing and are expected to result in similar levels of performance between males and females. Consistent with this, behavioural research shows that males tend to outperform females in spatial navigation tasks and path finding. This advantage is often attributed to the way in which they explore their environment, and in particular, to the use of survey spatial strategies, as evidenced by their tendency to travel longer distances without changing course, take fewer breaks, and make fewer returns to previously visited locations (Munion, 2019; Coluccia & Louse, 2004).

It is important to acknowledge that while males may display swifter movement, this advantage does not necessarily equate to more efficient navigation. Research has shown that males tend to excel over females in various spatial ability tasks, irrespective of size, with the gender contrast being more pronounced in larger-scale tasks (Voyer et al., 1995). Additionally, studies have indicated that males often exhibit greater accuracy in identifying critical elements in spatial navigation tasks (Astur et al., 2004). Moreover, nuanced findings have emerged from further investigations, revealing that males typically retain more route directions and favor mixed representations, whereas females tend to concentrate on landmarks (Lawton, 1994). It is essential to consider the influence of task type, familiarity with the environment, and cognitive abilities in shaping gender disparities in spatial behavior (Voyer et al., 1995). Furthermore, gender discrepancies in navigating virtual environments have been observed, with each gender demonstrating distinct strengths in utilizing global and local landmark information (Witmer & Kline, 1998). These differences are underscored by consistent findings of gender variations in navigating expansive virtual worlds (Friedman et al., 2006).

1.2.4 Neuroscience of Spatial Navigation

While early research on navigation primarily focused on rodents to establish fundamental insights (O'Keefe & Nadel, 1978), contemporary efforts have expanded knowledge employing diverse electrophysiological techniques to establish human spatial processes (Garcia & White, 2022). To this date, spatial navigation and wayfinding show intricately orchestrated brain regions, neural circuits, and cellular mechanisms that generated multiple theories supporting several navigation and wayfinding (Caplan et al., 2003; Bischof & Boulanger, 2003; Ekstrom et al., 2003).

At the core of spatial navigation lies the *hippocampus*, a pivotal structure renowned for its role in spatial memory and cognitive mapping, essential for comprehending allocentric data, spatial learning, and integrating contextual details (O'Keefe & Nadel, 1979; Bohbot et al., 2004; Hartley et al., 2003; Eichenbaum & Bunsey, 1995; Stepankova et al., 2004). Complementing this discovery, Moser et al. (2005) identified grid cells in the *entorhinal cortex*, providing a grid-like representation of space essential for spatial mapping and path integration enriching the neural representation of spatial boundaries and orientation. Recent research has furthered our understanding revealing complex forebrain circuits and identifying the hippocampus and entorhinal cortex as key regions for representing future goal locations (Cain, 1996; Spiers, 2015). O'Keefe and Dostrovsky's seminal discovery of place cells in the hippocampus unveiled neurons' selective firing patterns corresponding to specific locations within an animal's environment, thereby laying the foundation for understanding spatial representation at the neural level (O'Keefe & Dostrovsky, 1971).

Collaborative involvement of *medial, temporal, parietal, and frontal* brain regions has been observed in facilitating route following, decision-making, and sensorimotor integration for navigation (Corbetta & Shulman, 2002). Lesion overlap highlighted the crucial role of the *hippocampal formation, posterior parietal cortex, and dorsolateral prefrontal cortex* in spatial working memory planning and decision-making (Maguire et al., 1998; Hartley et al., 2003; Burgess et al., 2001; van Asselen et al., 2006; Abrahams et al., 1999). The *prefrontal cortex* (PFC) also plays a significant role, with the *dorsolateral PFC* (dlPFC) and *ventrolateral PFC* (vlPFC) are involved in inhibition and replanning integrates spatial information with higher-order cognitive processes such as working memory and executive functions, facilitating decision-making and goal-directed navigation. The *dorsal anterior cingulate cortex* (dACC) is involved in planning and route changes, while the orbitofrontal cortex (OFC) in integrating environmental representations with action value (Heilbronner & Hayden, 2016). Cellular mechanisms like long-term potentiation (LTP) and long-term depression (LTD) underlie synaptic plasticity critical for encoding and consolidating spatial information (Bliss & Collingridge 1993). Additionally, the parahippocampal cortex, retrosplenial cortex, dorsal striatum, and posterior parietal cortex have been identified as providing complementary functions in spatial navigation as well (Baumann, 2021). The *parahippocampal place* area (PPA) and the *retrosplenial complex* (RSC) are crucial for representing the local visual scene and situating it within the broader spatial environment, respectively (Epstein, 2008), while *the striatum,* encompassing the caudate nucleus and putamen, contributes to spatial navigation through reward-based learning and habit formation. Dopaminergic projections to the striatum play a crucial role in modulating reinforcement learning processes associated with navigation. Finally, at the core of the motivational mechanism lies the brain's reward system, with key players like the *ventral tegmental area* (VTA) and *the nucleus accumbens* (Berridge & Kringelbach, 2015). In complex these areas work together to allow successful trajectories, strategies and navigation.

1.3 DYNAMICS OF EMOTIONAL PROCESSING

1.3.1 What are Emotions?

We have highlighted evidence that explains the complex human ability to navigate in space. Navigation often involves the processing of a variety of external stimuli. While some stimuli may be neutral in their valence and meaning, other stimuli are characterised by a deep social value. A clear example is the emotional state of others, especially as expressed by faces (Ekman, 1993). Such stimuli could influence and modulate navigation. In the following chapter we will consider the influence of emotions and their expressions on human cognition and behaviour.

Emotions are strong and immediate states of feeling conveyed primarily through facial expressions that can carry a wide variety of information (Darwin, 1872; Langfeld, 1918). They are considered to be relatively short-lived mental states that trigger changes in motor behaviour, physiological changes, and cognitions (Hess & Thibault, 2009; James, 1884). They often result from the perception of an event or situation and play a crucial role in shaping human behaviour and responses to the environment (Ekman, 1992).

Emotion researchers Ekman and Rosenberg (2005) have played a pivotal role in advancing our understanding of emotions through the *Basic Emotions Theory*. This theory posits the existence of core, universal emotions such as happiness, sadness, anger, fear, surprise, and disgust, each of which is accompanied by distinct facial expressions (Ekman & Rosenberg, 2005). These emotions (see Figure 1.2) serve as basic building blocks that enable individuals to universally recognise and understand the emotional experiences of others. This theory emphasises the recognisability of facial expressions associated with each emotion, facilitating the identification, and understanding of emotions across cultures. This model introduces the concept of emotional dimensions, categorising emotions based on factors such as intensity, valence, and arousal (Ekman & Rosenberg, 2005; other models have been proposed based on different grouping criteria, e.g. Mesquita & Boiger, 2004; Ortony & Turner, 1990; Scherer, 2000). Indeed, emotions involve complex sets of characteristics to be identified. *Valence*, for example, denotes the inherent positivity or negativity of an emotion (Russell, 1980). *Arousal*, on the other hand, measures the intensity or activation level of an emotion, ranging from mild and barely perceptible to intense and overwhelming, with excitement and anger being examples of high-arousal emotions and relaxation and contentment reflecting low-arousal states (Lang, 1995). Duration, complexity, expressiveness, and subjectivity must be also considered. Emotions can be divided into negative and positive experiences. Negative emotions include feelings such as sadness, anger, fear, disgust, anxiety, guilt, and shame, often in response to undesirable situations or losses. Positive emotions include happiness, love, gratitude, interest, excitement, pride, and contentment, typically resulting from pleasurable experiences or achievements. Both negative and positive emotions are integral to human life, serving as signals that guide our responses and facilitate communication, decision making, and general well-being (Ekman & Friesen, 1971; Izard, 1980).

Emotion processing involves *generation, perception, recognition, expression, interpretation, and regulation* of our own and others' emotional experiences (Keltner & Gross, 1999). Generating an emotion is influenced by a range of cognitive, physiological, and environmental factors, with specific brain regions, culture and society all contributing (Mesquita & Frijda, 1992; Costa & McCrae, 1985). Competing hypotheses of emotion generation have claimed that it is based either on subjective appraisals of events that are not necessarily emotion-specific (e.g., Frijda et al., 1989; Scherer, 1984), or on categorical emotion-specific responses (e.g., Ekman & Friesen, 1976).

Appraisal theories, such as Scherer's (1984) Component Process Model, suggest a combination of cognitive, physiological, and motor behaviours that follow the subjective evaluation of an event. Appraisal theories of emotions suggest that valence alone does not automatically influence behavioural reactions (fight/flight). Instead, the effectiveness of emotional stimuli in affecting other cognitive processes might depend on their emotional relevance to the subject's goals (Mancini et al 2020). In contrast, accounts of emotion expression based on discrete categories have been supported by innate and universal recognition of prototypical emotion displays (Izard, 1994). Specific events are thought to elicit corresponding bodily responses, which are reflected in specific emotion displays that are universal. For example, a fire in a building may elicit a fight/flight response, tensing of facial muscles, increased heart rate, or jittery behaviour, which collectively convey the emotion of fear and anxiety. Physiological markers of emotional experience include facial expressions, non-verbal components of vocal expressions, galvanic skin response, respiration, heart rate, body posture, and muscle movement (Banse & Scherer, 1996; Barrett et al., 2011; DePaulo & Friedman, 1998; Ekman & Rosenberg, 2005). Any of these changes can provide visible cues to others, even if they are not necessarily intended for an audience. Indeed, emotions produced in different social settings are often interpreted as different communicative acts, independently from their relevance to the subject's goals and this in part may be critical for spatial navigation processes.

Then, why do we experience emotions? It seems obvious that such an overwhelming experience may have chief evolutional, social, and psychological functions. *Emotional experience* mainly creates urges that need to be released or contained (Jang & Elfenbein, 2015), therefore, each individual emotion is associated with specific action tendencies (Frijda, 1986), which are psychological and physiological responses that prepare individuals to respond adaptively to the most pressing issues in their environment (Cosmides & Tooby, 2000; Scherer et al., 2013). The social-functional perspective on emotions argues that these action tendencies serve functions in promoting group life that significantly enhances survival (Morris & Keltner, 2000). Even if an emotion does not appear to be functional in every instance, it remains available in the repertoire because in some cases it helps social groups, such as family units, to thrive or simply remain intact. However, the ability to express emotions changes throughout life and may depend to some extent on social factors or past experiences and subsequent positive or negative reinforcements (Dollard & Miller, 1941).

When emotions are expressed, they are also perceived by others (Keltner et al., 2019). As emotions are also a form of communication, observing, processing and interpreting emotional expressions is fundamental to recognising and responding to the emotional states of others. *Emotion recognition* and social behaviour are closely intertwined. Facial expressions have the capacity to evoke empathy and compassion, which promotes social bonding and allows individuals to offer support and assistance to those in need (Singer & Lamm, 2009). These effects extend to *emotional contagion*, where individuals may resonate with the emotions expressed by the person in the negative facial expression, potentially resulting in a shared emotional experience and influencing their behaviour (Hatfield et al., 1993). These in turn influence social behaviour, including empathy, prosocial behaviour, and emotional contagion, where individuals tend to 'catch' the emotions of those around them (Adelhöfer et al., 2019). Negative facial expressions, for instance, can affect trust and cooperation in social interactions, potentially leading to reduced trust and cooperation when displayed, as they may signal potential conflict or hidden motives (Brebner & Cooper, 2004).

Our understanding of others' emotions is likely to be related to so-called 'mind-reading' processes (Goldman & Sripada, 2005). Emotions can be recognised by inferring mental states in others on the basis of one's own knowledge. In the case of facial expressions, one would link the observed emotion to a repertoire of previously known emotion categories in order to classify the observed emotion. Simulation theories describe emotion recognition as a process of simulating and replicating the behaviours and states of others (Goldman & Sripada, 2005). An example of mind reading is *Theory of Mind (ToM)*. According to Baron-Cohen, Leslie, and Frith (1985), ToM is a "mechanism that underlies a crucial aspect of social competence, namely the ability to infer mental states: that is, to know that other people know, want, feel, or believe things" (p. 38). Thus, ToM and perspective taking are crucial to understand the emotional states of others, indeed, there seems to be a relationship between impaired emotion recognition and ToM deficits in autistic children (Baron-Cohen et al., 1985; Heerey et al., 2003) or schizophrenic patients (e.g., Bruene, 2005). Even if emotion perception can occur without mentalising about others' states and ToM comes later and requires a higher level of engagement (Mitchell & Philips, 2015) being fundamental for understanding others' emotions.

In general, ToM abilities are associated with activity in the medial prefrontal cortex (Gallagher et al., 2000). Recent advances in neurophysiological research in monkeys have highlighted the mirror neuron system (MNS) as a key player in simulation-based approaches to emotion recognition. *Mirror neurons*, located predominantly in motor areas, are known to fire when observing the actions of others, providing individuals with an understanding of the intentions behind these actions (Rizzolatti, 2005). The mirror neuron circuit, which includes parts of the premotor cortex and the inferior parietal lobe, plays a central role in various aspects of social functioning, such as imitation, learning and fostering interpersonal relationships (Fabbri-Destro & Rizzolatti, 2008). The importance of the MNS is particularly evident in its ability to elucidate why and how people recognise emotions in others. The insula and anterior cingulate cortex are key components of the MNS and are activated not only during the direct experience of disgust, but also when observing others expressing the same emotion (Wicker et al., 2003; Jabbi et al., 2007). Further supporting this link, damage to the insula led to a reduction in disgust across modalities, reinforcing the role of the insula in the processing and recognition of emotions (Calder et al., 2000).

Figure 1.2. The seven universal facial expressions of emotion. Retrieved from Matsumoto & Ekman (2009). Oxford University Press.

1.3.2 Negative Facial Expressions: Why Fear and Anger

Since emotions have differing affective valences, motivational directions, and opposite arousals (Harmon-Jones, 2017) reported to both facilitate and impair various cognitive processes (Vogel & Schwabe, 2016) we wondered whether specifically negative facial expressions could influence spatial navigation, and if so how. Fear and anger are of particular importance for the avoidance of threats and dangers (Sander et al., 2013). As these are the main focus of the present dissertation, we will discuss them in detail.

In everyday social interactions, we not only recognise faces in our environment, but also identify their emotional expressions in context. Previous research has shown that negative emotions provide information about a source of threat in close proximity. This ability gives us an adaptive advantage by predicting future actions and adjusting our behaviour accordingly (Gonzalez-Garrido et al., 2013). For example, when travelling along a route and encountering strangers who display emotional reactions, our attention is drawn in diverse ways. The sight of an angry face may raise concerns about potential aggression, while a frightened face prompts the need to determine its cause and assess its implications for our well-being and that of others. Conversely, a smiling face might be perceived as a signal of safety, indicating that there is no imminent danger. Therefore, when we travel and spot threat-related expressions in others, decision making might become difficult, leading to geographic disorientation and potentially compromising our safety. In such cases, individuals may react impulsively, driven by survival instincts, being influenced by fight-or-flight responses (Ekman, 1993). Alternatively, such emotions might facilitate the generation of successful trajectories that adapt to environmental changes, demonstrating the ability to act despite feelings of uncertainty (Tenbrink, 2020). Both potential reactions might be of particular interest for wayfinding abilities.

Negative facial expressions of others attract attention and influence decisions and behaviour to address or avoid perceived threats or challenges (Sander et al., 2005). Previous studies have shown that we can detect and reliably classify most emotional expressions of others in a neutral environment (e.g., Ekman & Friesen, 1978; Herba & Phillips, 2004). As evidence of the communicative relevance of others' emotions, faces are perceived within milliseconds. ERP studies suggest that emotionality in faces can be detected as early as 100 ms after stimulus onset, while discrimination between specific emotion categories occurs as early as 140 ms after stimulus onset (Batty & Taylor, 2003). The processing of emotional expressions and the structural encoding of faces are parallel processes, with early emotional ERP modulations reflecting the rapid activation of prefrontal areas (Eimer et al., 2003). Even newborn infants pay particular attention to human faces, as evidenced by increased eye-tracking behaviour of moving face patterns compared to non-face patterns, suggesting an innate ability to recognise the structure of human faces and discriminate between distinct types of facial emotions expressed (Morton & Johnson, 1991).

Gaining insight into the emotional states of others provides a survival advantage because a functioning society requires coordination between individuals (Burrows, 2008). Thus, we need to quickly classify emotions in order to recognise threats, assess social situations and behave accordingly, for example by protecting our offspring from predators. It is possible that general evolutionary mechanisms direct attention to such emotions, thus individuals are prepared to avoid threatening stimuli using the emotions of others as a guide. Indeed, compared to other emotional expressions fear and anger show sounder evolutionary implications for both communication and survival (Darwin, 1965/1872; Hampson et al., 2006).

The influence of *fearful facial expressions* on cognitive and behavioural processes is a complex and multifaceted, as evidenced by the wide literature in regards. Arterberry and Bornstein (2023) showed that five-month-old infants preferentially searched for novel fearful facial expressions compared to familiar static happy facial expressions. These findings suggest that from a very early age we can discriminate between different facial emotion categories, which may be an innate survival trait, but also that fearful expressions are salient and induce a heightened state of vigilance, affecting attentional focus (Dennis & Chen, 2007; Beauregard et al., 2001). This is supported by Peltola (2008), who found that fearful faces modulate gaze duration and attentional lapses in 7-month-old infants, suggesting an early influence of these expressions on visual attention. Consistently, fearful faces are detected 150 to 200 ms after stimulus onset (Kiss & Eimer, 2008). Furthermore, categorisation of faces with fearful (vs. neutral) expressions is fast, even when presented in peripheral locations (Rigoulot, 2011). Susskind et al. (2008) showed that fearful facial expressions are configured to enhance sensory acquisition: when perceiving fear (vs. disgust), people had a larger visual field, faster eye movements during target localisation, and increased nasal volume and air velocity during inspiration. Carlson and Reinke (2010) found that fearful faces can enhance spatial attention and facilitate orientation, with the latter study specifically highlighting the role of the fearful gaze in this process. Ellena (2021) further demonstrated that fearful faces can modulate spatial processing in peripersonal space, particularly in the context of potential threat. This effect was found to be particularly pronounced when the fearful face was presented in near space. Jiang et al. (2018) added to this body of work by showing that even fearful faces presented subliminally can influence the allocation of attentional resources, with a significant decrease in the amplitude of the steady-state visual evoked potential after the appearance of the fearful face. Taken together, these findings suggest that fearful facial expressions have a significant impact on various aspects of spatial processing and spatial attention. Fear, when perceived in others, usually triggers a heightened vigilance, leading to a broader scope of attention. It enhances perception of potential threats in the surroundings, which can enhance spatial awareness (Ishikawa et al., 2021). Vlamings et al. (2009) explored this further and showed that fearful facial expressions modulate early brain activity primarily through low spatial frequency information (low spatial frequencies carry information about the configural properties of facial parts such as the eyes, nose, and mouth, Goffaux et al., 2005).

According to research, emotional stimuli, such as fearful facial expressions, can negatively affect working memory performance, especially when the emotional content is irrelevant to the task (Dolcos & McCarthy, 2006). The perception of a fearful facial expression may activate neural circuits associated with threat detection and response, leading to increased arousal and vigilance. This state of heightened arousal may interfere with encoding or retrieving visuospatial information by shifting cognitive resources towards threat detection and away from the working memory task (Pessoa et al., 2002). Fearful faces tend to capture attention and engage cognitive resources, thereby impacting working memory processes (Dolcos & McCarthy, 2006). It is important to note that faces with emotional valence, as opposed to neutral faces, can significantly impact visual working memory (VWM) and its associated costs (Curby et al., 2019). Emotional attentional blink, also known as emotion-induced blindness, is a phenomenon where a task-irrelevant, emotionally arousing image briefly captures attention to such an extent that individuals fail to detect target stimuli for several hundred milliseconds after the emotional stimulus. This reflects interference of emotional content with the encoding and maintenance of visual information in working memory (Most et al., 2005; McHugo et al., 2013).

The *perception of other's anger* may significantly influence cognitive abilities, although the literature in this area is sparse (see Richard et al. 2023 for a review). Angry faces, similar to fearful expressions, are evolutionarily salient stimuli that can capture attention due to their perceived threat implications (Fox et al., 2000). Angry faces are typically more salient than other stimuli in visual search tasks for emotional faces (Hansen & Hansen, 1988). This increased salience may be influenced not only by the inherent threat of angry faces, but also by individual experience. For example, police officers show an enhanced ability to detect angry faces in a riot crowd compared to laypeople (Damjanovic et al., 2014). However, this hyper-focus on threat cues may potentially limit spatial awareness by narrowing attention to anger-related stimuli (Ishikawa et al., 2021). Furthermore, the perception of anger may activate neural circuits associated with threat detection and response, resulting in heightened arousal and vigilance (Pessoa et al., 2002). Electrophysiological studies have observed that N2pc amplitudes occur earlier and with greater amplitude when detecting angry versus happy faces, suggesting increased attention for threatening faces (Weymar et al., 2011).

Perceiving anger can significantly influence visuospatial working memory, through various mechanisms (Fox et al., 2000; Pessoa et al., 2002; Chester & DeWall, 2016). The salience of angry faces can lead to a temporary interruption or disruption of ongoing visuospatial processing, diverting cognitive resources towards threat detection (Fox et al., 2000). This impairment may be due to the consumption of cognitive resources by the processing of angry faces, reducing the capacity available for maintaining visuospatial information (Dolcos & McCarthy, 2006). In addition, the negative emotional state induced by angry faces may lead to interference effects in visuospatial working memory tasks, disrupting the cognitive processes necessary to maintain and manipulate other visuospatial information (Vuilleumier et al., 2001). Specifically for visual working memory, Jackson (2009) found that a greater number of angry face identities can be stored in visual working memory compared to happy or neutral faces, a finding supported by Thoma et al. (2014), suggesting that we are particularly attuned to devote cognitive resources to this type of emotional face. Besides, individuals with higher trait anxiety scores have shown better visuospatial working memory for angry faces (Gambarota & Sessa, 2019), unlike fearful faces (Moriya & Nittono, 2011). Simione et al. (2014) found that the position of angry faces in an array was better remembered than that of neutral faces. However, the position in space of fearful faces may be better remembered than that of angry faces in neutral conditions, as indicated by distress-related physiological responses (Putman, 2007). VWM preferences for angry faces indeed can be modulated by the affective context (Maran, 2015).

Some studies tested the influence of these emotional faces with behavioural measures (Tyng et al., 2017; Ye et al., 2020; Adams et al., 2006; Stins et al., 2011). Seidel (2010) showed that happiness and arousal are typically associated with approach behaviour and risk-taking decisions, whereas fear and anger are associated with avoidance responses. However, contrary evidence suggests that fearful facial expressions can elicit approach behaviour, possibly due to their similarity to infant faces (Hammer, 2015). This may be because fear elicits affiliative helping intentions (Marsh, 2005). However, both fear and anger elicit avoidance when presented with positive emotions, underlying the importance of the valence contrast between different emotional expressions for determining behavioural reactions (Paulus & Wentura, 2016). Perceived fear can also increase motor and response inhibition (Choi & Cho, 2020). Mirabella (2018), using a Go/No-Go task focused on reaching arm movements, demonstrated that fearful faces increased error rates and reaction times more than happy faces, particularly when task relevant. Mancini et al. (2020) and Mirabella et al., (2023) obtained similar results with angry facial expressions on a measure of forward gate-initiation.

1.3.3 Gender Differences in Emotion Processing

Previous research has shown that gender differences characterise emotion processing and, in particular, emotion recognition. In a meta-analysis, Thompson and Voyer (2014) suggested that there may be a female advantage in recognising non-verbally presented emotions, but the magnitude of the effect depended on interactions between the specific emotion and the modality of presentation. In general, females seem to be better at recognising emotions from faces, voices, and audiovisual presentations (Collignon et al., 2010), although such differences are not always observed equally across all modalities (Hawk et al., 2009; Lambrecht et al., 2014). Compared to males, females also appear to use different visual features in the face for recognition, such as the mouth area (Blais et al., 2013). The female advantage is pronounced when stimuli are presented for a longer time (Thompson & Voyer, 2014; Sullivan et al., 2017; Olderbak et al., 2018), probably due to greater benefits from encoding/encoding mechanisms (Weirich et al., 2011), but also when information is only partially available (Kret & De Gelder, 2012; Abruzzese et al., 2019; Manstead, 1992; Rahman et al., 2004).

One reason to expect gender differences in emotion recognition may be related to the 'primary caretaker hypothesis' (Babchuck et al., 1985), according to which females 'exhibit evolved adaptations that increase the likelihood of survival of their offspring' (Hampson et al., 2006, p. 402). This could be reflected in enhanced emotion recognition by females to ensure the well-being of their offspring. Significant gender effects could demonstrate adaptive parenting mechanisms in female participants by correctly classifying others' emotions displayed in faces. However, females may also have higher levels of emotionality and arousal, which may lead to worry-related thoughts that affect WM processing, resulting in attentional biases towards emotional stimuli (Saylik, 2018).

It has been proposed that females' facial emotion classification may be to some extent automatic. For example, subliminally presented emotions elicited correct accuracy ratings above chance in females but not in males (Hall & Matsumoto, 2004). On the other hand, males are often less accurate and sensitive in labelling facial expressions, although they have been shown to be more responsive to threatening, violent or aggressive cues, even when these are subtle and ambiguous (Fischer et al, 2018; Montagne et al, 2005). Furthermore, De Gelder et al. (2010), who recorded the BOLD responses of participants watching male and female actors expressing threat, observed that threatening male bodies elicited the highest activity in the superior temporal sulcus of male participants, whereas the amygdala was more active for facial than for bodily expressions, particularly for male observers of female faces. This suggests interesting gender-specific activations in threat perception.

Indeed, research consistently shows that there are also gender differences in regulation of emotional reactions. Females tend to show increased amygdala reactivity compared to males (Stevens & Hamann, 2012), who also show greater activation in prefrontal cortex regions during negative emotion processing tasks (Stevens & Hamann, 2012), suggesting more regulatory strategies when processing negative emotions in females. Brody et al., (1985) suggested that these differences may be due to socialisation processes and innate gender differences in temperament. Deng et al. (2016) added to this by showing that men often have more intense emotional experiences, while women have higher emotional expressiveness, especially for negative emotions. Overall, emotional stimuli, particularly faces, are an undeniable source of information for managing our interactions with the environment. Taken together, these findings suggest that gender differences in emotional behaviour are complex and influenced by a variety of factors.

1.2.3 Neuroscience of Emotional Processing

Emotional recognition and processing involve a network of brain regions that work together to perceive, interpret and respond to emotional stimuli. One of the key structures involved in emotional processing is the amygdala. The *amygdala* is known for its role in detecting and processing emotional information, particularly in response to threat or fear (LeDoux, 2000). It plays a crucial role in the generation of emotional responses and in associative learning, linking specific stimuli with emotional meaning. In addition, the *hippocampus* participates in the formation and retrieval of emotional memories, associating contextual information with emotional experiences and modulating the expression of emotions based on past experiences (Dolcos et al., 2004; Fanselow & Dong, 2010; Bannerman et al., 2004). The *prefrontal cortex (PFC),* in particular the *ventromedial prefrontal cortex (vmPFC)* and the *orbitofrontal cortex (OFC)* are involved in the regulation of emotions and the evaluation of emotional stimuli (Phan et al., 2002). The PFC is also critical for decision-making processes that involve weighing emotional information against other factors. In addition to the PFC, vmPFC and OFC, the basal ganglia, including structures such as the striatum, are also involved in emotional regulation and decision-making processes (Phan et al., 2002). The PFC regulates emotions and evaluates emotional stimuli, while the basal ganglia process reward and punishment signals that are integral to emotional responses and play a role in motivation, reinforcement learning, and the generation of approach and avoidance behaviours. In addition, the hypothalamus regulates autonomic and endocrine responses to emotional stimuli, coordinating physiological changes associated with emotional arousal, such as the release of stress hormones.

The *fusiform face area (FFA)* is involved mainly in facial recognition, but it also plays a role in processing emotional expressions conveyed through faces (Kanwisher et al., 2006). The *anterior cingulate cortex (ACC)* is implicated in emotional monitoring processing, and regulation of emotional conflict, as well as regulation of emotional responses (Etkin et al., 2011). It plays a role in attentional control and modulation of emotional responses based on contextual information. In addition, the *insula* controls the perception and awareness of one's own emotional states, engages in subjective feelings of emotion, and is responsible for integrating visceral sensations with emotional experiences (Craig, 2009). Finally, the *thalamus* serves as a relay station for sensory information, transmitting emotional signals to the cortex and other subcortical structures for further processing. These brain regions form complex neural networks that underlie the processing and regulation of emotions. Dysfunction in these circuits can contribute to several emotional disorders, including anxiety, depression and post-traumatic stress disorder (PTSD). While there is some overlap in the brain regions involved in processing emotions*,* different patterns of activation within these regions are observed depending on the valence of the emotion. Negative emotions, such as fear and anxiety, are primarily processed by regions such as the amygdala, which is central to detecting and responding to threatening stimuli (LeDoux, 2000), whereas the ACC regulates responses to negative emotions, including fear and pain (Etkin et al., 2011). The insula is involved in processing negative experiences such as disgust and aversion (Craig, 2009), while the hypothalamus regulates physiological responses to stress and negative emotional states through the release of stress hormones (Ulrich-Lai & Herman, 2009). In contrast, positive emotions, such as happiness and pleasure, are associated with activation of the PFC, vmPFC and OFC, which participate in processing positive emotions, reward and reinforcement learning (Phan et al., 2002). Likewise, the striatum engages in reward and the experience of pleasure (Delgado, 2007), the mPFC in feelings of belonging and reward, while the nucleus accumbens is central to reinforcement and pleasure (Berridge & Kringelbach, 2015).

With regard to negative emotions, the amygdala is emerging as a central player in the perception, detection and processing of fearful stimuli (Davis, 1992; LeDoux, 2003) and is thought to modulate the visual encoding of salient social information, even when it is outside the focus of attention (Morris et al., 1996; Furl et al., 2013). Its modulatory role extends to connections with primary visual and prefrontal areas, highlighting its involvement in the coordination of cortical networks during danger and threat assessment (Morris et al., 1998; Pessoa and Adolphs, 2010). Lesion studies consistently show that bilateral damage to the amygdala results in a more generalised reduction in emotion recognition ability, particularly for negative emotions, with the most pronounced impairment observed in the recognition of fearful faces (Adolphs, 1999). This impairment extends to different modalities, including prosody for fearful emotion processing (Phillips et al., 1998) and non-verbal affective bursts expressing fear and anger (Scott et al., 1997). Beyond the amygdala, the orbito-frontal regions of the brain have been implicated in general emotion recognition abilities across faces, with a specific association with the recognition of angry faces (Blair et al., 1999). Angry stimuli also activate the anterior cingulate cortex, suggesting a nuanced relationship between anger, sensory modalities and specific brain regions. It has been suggested that frontal areas of the brain may be primarily involved in higher cognition, including conscious evaluation of the classification of emotional stimuli, especially when faced with ambiguous stimuli such as affective prosody that require further evaluation (Nakamura et al., 1999; Leitman et al., 2010). Furthermore, the right somatosensory cortex emerges as a critical player in the processing of emotion in faces, with lesion studies suggesting that impairment of this region is associated with a deficit in the formation of neural representations of observed emotions (Pitcher et al., 2008).

Meta-analysis findings indicate that females tend to display greater activation in regions associated with negative emotion, such as the left amygdala, left thalamus, hypothalamus, and medial prefrontal cortex, compared to men. Conversely, males tend to exhibit greater activation in response to positive emotion, particularly in regions like the bilateral inferior frontal gyrus and right fusiform gyrus, including the left amygdala. This valence-specific pattern suggests that gender differences in emotional processing are not uniform across emotions but rather depend on the emotional valence of the stimuli. These findings underscore the importance of considering valence when examining gender differences in emotion processing, particularly regarding the amygdala, a key region implicated in emotional processing (Stevens et al., 2012).

According to the right hemisphere dominance hypothesis, emotions are primarily processed in the right hemisphere of the brain, regardless of their valence or specific type. In contrast, the valence lateralization hypothesis proposes that different emotions exhibit distinct lateralization patterns based on their positive or negative valence. Positively valenced stimuli, associated with approach behavior, are thought to be processed predominantly in the left hemisphere, while negatively valenced stimuli, associated with withdrawal behavior, are processed mainly in the right hemisphere (Davidson & Tomarken, 1989). While there is evidence that perceiving fear and anger in others can influence one's own cognition and behavior, likely due to their threat-avoidance significance, the traditional view of hemispheric dominance in emotion processing is being reevaluated in light of more complex neural networks. Instead of strict hemispheric specialization, emotion processing involves multiple interconnected networks responsible for generating, perceiving, and regulating emotions. These networks may not uniformly exhibit the same patterns of lateralization, challenging the notion of an overall hemispheric dominance for emotion processing (Pessoa, 2017).

1.4 THE PRESENT DISSERTATION

1.4.1 Research Questions, Open Issues and Aims

In our daily lives we are overwhelmed by a vast amount of information, such as people, road signs, flashing lights and sudden sounds. While some stimuli may be neutral in their valence and meaning, other stimuli have a deep social value. A clear example of this is the emotional state of others, especially that expressed by their faces (Ekman, 1993). In threatening or everyday scenarios, other people's facial expressions serve as an important source of information about what is happening. To our knowledge, although several studies have investigated spatial navigation and orientation (Burgess, 2008; Wolber, 2015; Epstein, 2017; Ekstrom et al., 2018), research on the impact of facial emotion processing and the consequences of exposure to others' negative emotions on navigational abilities has been largely neglected (Pessoa, 2012; Zhao et al., 2024; Ruotolo et al., 2018). In this dissertation, we propose to integrate these two separate lines of research and provide a first investigation of the role of negative emotions on wayfinding, spatial navigation, and related abilities.

In order to evaluate the present research questions, we started with a preliminary exploratory approach and then developed clear hypotheses throughout the work. We attempted to conceptually replicate first exploratory findings with different methodologies, focusing on the elements of interest that explain our findings and coherently answer our research questions. Further and more detailed hypotheses for each experiment were developed sequentially and contextually in each introductory section. We deliberately focused on the perception, recognition and processing of others' emotions rather than mood or first-person emotional experience, as this was beyond our scope, wondering whether processing strangers' negative emotional expressions while completing spatial tasks might influence performance. Considering the overviewed literature, we examined differences due to stimulus type (face vs. others), emotion (anger vs. fear) and participant's gender in our findings. Here, we provide an overview of our research questions.

Our *first open question* concerns whether facial emotional expressions can *enhance or inhibit* the behavioural tendencies of participants asked to navigate an environment, potentially moderating the outcome of wayfinding performance. Although evidence suggests that spatial mapping is selective, flexible and adaptive, allowing us to encode only certain aspects of our environment, we can still be easily influenced by some especially relevant and attention-grabbing stimuli (Lichtenstein et al., 2012). As an example, if we engage in facial emotion processing during navigation, facial expressions might capture our attention and consequently influence working memory and visual perception due to their configurational features (Lepsien & Nobre, 2006). Previous research has shown that negative emotions provide information about a source of threat in close proximity; this ability gives us an adaptive advantage by predicting future actions and adjusting our behaviour accordingly (Gonzalez-Garrido et al., 2013). However, it is undefined if the performance on a navigational task might be enhanced or not because of a negative facial stimulus. When spotting a threatening stimulus during a navigation task, it might create uncertainty and increase the speed of decision making. In turn, this can lead to distraction and geographic disorientation. In such cases, individuals may react impulsively, driven by survival instincts and influenced by fight-or-flight responses (Ekman, 1993). Alternatively, processing the threatening stimulus can enhance attention and focus, and thus they may generate successful trajectories that adapt to environmental changes, demonstrating the ability to fulfil a goal (i.e., effective navigation) despite the interference (Tenbrink, 2020). Hence, do processing emotional facial expressions help or hinder spatial navigation?

Although the effect we are specifically interested in is whether human emotional stimuli influence navigation and spatial skills, it is also relevant to test the uniqueness of such an effect through a comparison with other types of stimuli. First, it is important to test the face-specificity of the effect. As the face, also the body emotional expressions of humans are a potentially relevant stimulus, and thus it might influence results in a similar manner (de Gelder & Van den Stock, 2011). So, a comparison with the effect of the body would provide a first answer. Second, it is crucial to determine the socio-emotional specificity of the effect. As navigation sometimes takes place in emotionally evocative contexts (e.g. sunny park, dark street), it may be that emotions evoked by the context itself can also influence navigation patterns. Indeed, serene natural outdoor environments may evoke feelings of calm and happiness, whereas busy urban indoor environments may lead to stress and anxiety (Ulrich, 1983). Since it configures as a non-human type of stimulus, the influence of such stimuli on navigation should also be addressed.

The second open question concerns possible differences between faces expressing either fear or anger. Research has highlighted possible similarities and differences in their effects on cognition and behaviour (e.g. Adams et al., 2006; Mirabella et al., 2023; Paulus & Wentura 2016; Seidel, 2010; Stins et al., 2011). They are more attention-grabbing than others, they require heightened vigilance and rapid detection, they may have higher task relevance even when not explained, they may elicit behavioural fight-or-flight responses or approach-avoidance tendencies; they may express a clear communicative message implying heightened vigilance and rapid detection of evolutionarily relevant fear stimuli in the same context to enhance survival (Öhman et al., 2001). They are also identified with greater accuracy and speed than other changing objects in the environment (Jenkins et al., 2005; Reinders et al., 2005). However, to our knowledge, no study has compared the effect of processing fearful and angry faces in spatial navigational tasks. Processing anger and fear in others may have different behavioural effects. Studies of behavioural tendencies have shown avoidance in response to angry facial cues (Dimberg et al., 2000), and approach towards others' fearful faces due to affiliative intentions (Marsh, 2005). Fear reflects a broader, potentially ambiguous threat, implying a more general threat in the environment, related to an unidentified source of danger. Whereas anger is typically associated with a more immediate and direct threat to the observer, often signalling aggressive intentions or hostility on the part of the person expressing anger (Ekman & Friesen, 1976). Anger may be associated with confrontational threats, so responding to expressions of anger may be more adaptive when dealing with interpersonal conflict (Adams et al., 2006). Furthermore, both may potentially drain cognitive resources from the VSWM essential for navigation (Brown & Chrastil, 2019; Tyng et al., 2017). The overlaps and similar effects leave us with an open question without a clear directional hypothesis about their effects on navigation. Therefore, we will explore their differences in our first investigations, and later we will attempt to test the robustness of such findings.

The third question concerns gender differences that are expected to modulate spatial navigation and the effect of processing negative facial emotions on it. It has been shown that of all the different cognitive systems, the most pronounced gender differences are those related to spatial skills and social cognition (Lowe et al., 2003). Overall, we expect males to outperform females in spatial navigation and VSWM tasks, demonstrating greater accuracy through effective use of survey spatial strategies (Coluccia & Louse, 2004; Clint et al., 2012; Yuan, 2019; Kim, 2007). Females, on the other hand, may demonstrate greater navigational efficiency, particularly in response to negative emotional landmarks (Litvak et al., 2012). Gender differences and their effects on the interplay between these functions may be exacerbated also by neurological differences.

According to some findings, both navigation and emotion processes might have a predominant right lateralisation in males but not in females due to their bilaterality for emotional processing (processing (Clements et al., 2006; Jacobs et al., 2010; Kolb & Taylor, 2000; Castro-Schilo & Kee, 2010; Proverbio et al., 2006; Rilea, 2008; Persson et al., 2013). These mechanisms might interfere when pitted against each other, leading to performance impairments (Hartikainen et al., 2000). Thus, for males more than females, engaging in subsequent high load tasks may result in poorer navigational performance following negative emotional processing. As there is still insufficient evidence to define a clear pattern of these navigational and emotional behavioural and cognitive tasks, an empirical approach is sought to explore such gender differences.

The fourth question is whether fearful or angry facial expressions can influence spatial navigation strategies and cognition, or in other words, its domains. As suggested by Claessen and van der Ham (2017), to determine and describe the full extent of these effects, investigations of spatial navigation should be extended to a variety of domains. Therefore, it is likely that emotional expressions influence not only behavioural outcomes, but also wayfinding domains such as landmark, location, and path knowledge. According to the previous research, a male advantage is more likely to be found in this sort of spatial tasks (Coluccia & Louse, 2004), although females may be better at landmark-based tasks (Sandstrom et al., 1998). Furthermore, there is evidence for a small male advantage in path route knowledge and location domains with allocentric reference (van der Ham et al., 2020). Therefore, we expected to observe a moderation of such results due to the exposure to emotional stimuli and to conceptually replicate a pattern in line with that of our first experiment (we include more details on our hypotheses in the introduction of Experiment 4).

The fifth and final question is whether the findings of our experiments might be due to the fact that both spatial cognition and emotion processing rely on VSWM resources. As both navigation and face processing rely on VSWM (Castillo et al. 2021; Ekstrom et al. 2018), the impairment caused by emotional faces may be due to competition for shared VSWM cognitive resources. A task with high cognitive load (e.g., emotional processing of fear) and competition for visuospatial resources might show limitations and impairments in performance in another VSWM task due to limited access to such resources. Negative facial expressions, such as fear or anger, have been found to impair VSWM performance by competing with other information in working memory and reducing its capacity (Ishikawa et al., 2021). Indeed, engaging in demanding VSWM tasks at the same time as processing facial expressions might lead to impaired performance on contingent and immediately subsequent tasks (e.g., Schmeichel, 2007). One possible explanation for this effect is that prioritised negative emotional stimuli - due to their threat value - may attract selective attention and consume resources that would otherwise be available for encoding or consolidating visuospatial information in working memory (Moran 2016; Shackman et al., 2006).

1.4.2 Overview of Aims, Chapters and Experiments

We aim to investigate the effect of negative facial expressions on spatial navigation skills and to determine whether fear or anger has different behavioural effects and whether they improve or impair wayfinding performance. To maintain the uniqueness of this work and to address our open questions, we will use different methods to measure behavioural and cognitive outcomes. We will compare the effects of exposure to negative emotions through emotional faces, contextual contexts, or emotional bodies to determine whether the effects are specific to facial expressions or a general response to the emotional cue. Furthermore, we will observe the effect of negative facial expressions not only on wayfinding by measuring its behavioural outcomes, but also on cognitive outcomes related to the three domains of spatial navigation: landmark, location, and path knowledge. This will allow an in-depth observation of the cognitive factors implied in the process compared to the behavioural outcomes obtained through real-time navigation in VR. Finally, we aim to uncover the mnemonic mechanisms responsible for the emotional impact on navigation by measuring VSWM performance after emotion processing. We outline the research questions and the aims of the present research in Table 1.1.

In Chapter 2, we investigate how negative expressions affect spatial navigation in three virtual reality experiments. In Experiment 1, participants entered a VR environment (i.e., a multi-storey office building) and were introduced to a wayfinding task consisting of first finding an object located in the environment (i.e., encoding, T1) and then finding the same object in the same location (i.e., retrieval, T2). Faces showing fearful, angry or neutral expressions were shown between the two phases in a task unrelated to wayfinding (i.e., gender categorisation). We measured travel time and distance travelled at T1 and T2 as behavioural outcomes related to participants' wayfinding performance (i.e., Burke et al., 2012; Dong et al. 2022) and investigated whether there were any differences due to emotional conditions and participants' gender. Then, using the same procedure, we conducted Experiment 2 (i.e., bodies with blurred faces) and Experiment 3 (i.e., contexts without humans) to determine whether the effect on wayfinding was face specific.

In Chapter 3 we investigated the effect of emotional face processing on different spatial navigation domains. Experiment 4 investigated in more detail which of the spatial navigation subcomponents are most affected by emotional (fearful vs. angry vs. neutral) facial expressions. Participants took part in an experiment in which they watched a video of a person walking to a target object, with the aim of remembering the route taken by the person in the video. They were then exposed to faces showing one of three emotions (i.e. fear, anger, neutral) and asked to perform a gender categorisation task. Finally, participants completed six tasks designed to assess their knowledge of landmarks, locations, and paths concerning the route shown in the video.

In Chapter 4 (Experiment 5), we investigated the cognitive factors, in particular the role of visuospatial working memory, which might explain our previous findings. The study investigated whether visuospatial resources could be subtracted when performing a visuospatial task with emotional faces. Participants' VSWM abilities, assessed by a Backward Corsi Block Tapping Task (CBT), were compared before and after a Delayed Non-Match to Sample Task (DNMS), which also taps visuospatial abilities, but modified to display either fearful, angry or neutral facial expressions. We therefore measured whether CBT performance at T2 was affected by exposure to the emotional (vs. neutral) faces, and whether performance on the DNMS was related to the latter.

In Chapter 5, we discuss our results and how they provide an answer to the open questions we addressed, and discuss implications, limitations, and further investigation of our findings.

Table 1.1 Open issues, aims, and chapters addressing them.

	Open Issues	Aims	Study
1.	Do emotional expressions (expressed by faces, bodies, scenes) impair or improve wayfinding?	To investigate the influence and differences between negative facial, bodily and contextual expressions on wayfinding in a virtual reality (VR) environment. We aim to compare behavioural outcomes of wayfinding after using facial vs. non-facial cues to express negative emotions.	1-2 3-4
2.	Do fearful and angry facial expressions affect spatial navigation differently?	To compare how fearful and angry facial expressions affect wayfinding by measuring reaction time and distance travelled in a VR task.	1-2
3.	Do gender differences matter?	Comparing the performance of males and females as a constant variable in all experiments.	All
4.	Do negative facial expressions affect navigation domains differently?	To compare how fearful and angry facial expressions affect navigational landmark, location, path knowledge using ad-hoc tasks.	5
5.	Do high cognitive load and competition for visuospatial resources affect results?	To compare how fearful and angry facial expressions affect visuospatial memory skills to provide a potential explanation of the results of the first experiments.	6

CHAPTER 2:

THE EFFECTS OF NEGATIVE EMOTIONAL PROCESSING ON WAYFINDING IN VIRTUAL REALITY

CHAPTER 2: EFFECT OF NEGATIVE EMOTIONAL PROCESSING ON WAYFINDING

2.1 Introduction

In this chapter, we present three experiments conducted in virtual reality that investigate the influence of negative emotions, conveyed through several types of stimuli, on wayfinding behaviour. Navigating in an unfamiliar environment requires continuous awareness of one's position relative to the environment in order to avoid getting lost. This ability is essential for situational awareness, planning and action readiness (Smith & Hancock, 2020). We are influenced by a considerable amount of information, but some may be more relevant than others in influencing navigation. Despite a growing body of research on spatial navigation (Burgess, 2008; Wolber, 2015; Epstein, 2017; Ekstrom et al., 2018), little is known about the effects of processing emotional cues from faces, bodies, or non-social stimuli (i.e., scenes) on these dynamics. Similarly, emotion research has overlooked the influence of emotion processing on navigational behavioural performance (Phelps, 2006; Pessoa, 2009). Therefore, the aim of this research was to determine whether the processing of negative emotions conveyed by different types of stimuli improves or impairs wayfinding in virtual reality, and whether there is face, gender, and/or emotion specificity. [1]

2.1.1 Spatial navigation and emotional face expressions

Spatial navigation is the process that underpins the ability to orient oneself in a familiar or novel environment, enabling travel in the real world (Brown & Chrastil, 2019; Diersch & Wolbers, 2019). It requires a wide range of cognitive abilities, including attention, memory, decision making, and problem solving (O'keefe & Nadel, 1978; Brodbeck & Tanninen, 2012). In this study, we focused on wayfinding behaviour (see Golledge, 1999; Farr, 2012; Wolbers, 2015), which is the ability to locate oneself in space using multiple sources of cues to determine the path to a destination and then travel to it (Ekstrom, 2018). Body-based self-motion cues and environmental information are integrated over time for effective wayfinding (Sjolund et al., 2018). As a higher-order function, it requires the ability to use different references in space (e.g., allocentric, egocentric), multiple integration processes (e.g., visual, proprioceptive, vestibular), and knowledge-based strategies (e.g., landmark, location, path) (van der Ham, 2020). These mechanisms enable direction estimation, position learning, error correction, location attainment, and destination recall, ensuring effective navigation (Montello & Raubal, 2013; Siegel & White, 1975). Behavioural measures of wayfinding performance include the time it takes to reach a destination and the distance travelled while searching for it (e.g., Burke et al., 2012; Coluccia & Louse, 2004; Dong et al., 2022; Saucier et al., 2002).

When navigating an environment, humans are often exposed to information from which they filter out those that are irrelevant to the task at hand (e.g., billboards, flashing lights, and sudden sounds) (Kunishige et al., 2020; Stangl, 2020). However, some information may be more evolutionarily, psychologically, and socially relevant than others: a clear example is the facial emotions of others (Ekman, 1993). Emotional faces are stimuli that can convey positive and affiliative, as well as negative and arousing, affects (Marsh et al., 2005). As part of everyday social life, people recognise faces in the environment and identify their emotional expressions and the spatial location in which they were seen with precision and speed (White & Burton, 2022).

[1] In all studies, both gender identification and sex assigned at birth corresponded, so we used the term gender to refer to both.

When walking down the street or entering a building, it is common to look at another person's facial expression to understand whether our own behaviour is appropriate to the situation around us (Langfeld, 1918). From a cognitive perspective, emotions are ubiquitous cues that influence spatial cognition and orientation among many human cognitive functions (Schupp et al., 2003; Pourtois et al., 2004). For example, Ruotolo, Claessen, and van der Ham (2019) tested the effect of emotional landmarks on a series of spatial memory tasks. They found that the location of positive landmarks is remembered more accurately than the location of neutral and negative landmarks, but routes with negative landmarks are remembered as having taken longer to travel than those with the other landmarks (see Piccardi et al., 2020; Rasse et al., 2023). Such a study is one of the few to show that spatial memory, one of the functions necessary for wayfinding (van der Ham, 2020) can be influenced by emotional cues. However, testing the effect of emotion elicited by emotional objects (e.g. dogs, books, guns) on spatial memory is not the same as testing the effect of emotion perceived specifically from faces, especially when it comes to wayfinding behaviour in realistic environments. Wayfinding research has highlighted the critical role of social interactions, often driven by emotions, as a potential influence on decision-making during navigation (Dalton et al., 2019). To our knowledge, the consequences of exposure to other people's emotions on wayfinding behaviour have been little explored, and therefore an investigation of the consequences is needed to begin to fill such a gap.

We are interested in the effect of negative facial expressions (i.e., fear and anger). There is a consensus among researchers that they influence people's behaviour significantly more than neutral or positive ones (Stins et al., 2011). The ability to communicate and perceive emotions is thought to be a significant adaptive advantage for humans and animals in predicting the future actions of others and adjusting one's own behaviour accordingly (Gonzalez-Garrido et al., 2013). Evolutionarily, people's attention to such facial cues stems from their ability to detect threats for survival advantage, even when the exact nature of the threat is only partially understood (Adolphs, 2008). Indeed, negative emotions should be detected quickly and effectively in order to activate motor responses (e.g. fight/flight, Öhman et al., 2001). However, such motor responses differ depending on the perceived emotion. Research suggests that the perception of fear in another person's face, which may indicate a source of threat in the environment (e.g., someone is being chased by a dangerous animal), may lead to approaching behaviour towards conspecifics to help, whereas the perception of anger in another person, which may signal an intention to attack, may lead to avoidance behaviour to escape the immediate confrontation (Marsh et al., 2005). However, not all findings are consistent: Adams et al. (2006) suggested that fearful faces may instead elicit freezing responses (i.e., behavioural inhibition; but see Bossuyt et al., 2014).

Consistently, exposure to a fearful face during a response inhibition task has been shown to improve the ability to inhibit a motor response (Choi & Cho, 2020). Mirabella (2018), using a Go/No-Go task, showed that fearful faces increased error rates and reaction times more than happy faces, and Mancini et al. (2022) showed that fearful faces improved inhibitory control compared to happy faces, but only when emotions were relevant to the task (see Mancini et al., 2020, for a comparison with angry faces; see also Mirabella et al., 2023). Interestingly, the perceived contrast between fear and anger (and other emotions) can also influence behavioural responses: when fearful and angry expressions are presented in the same task and there is no comparison with a positive emotion (i.e., happiness), anger leads to approach and fear to avoidance, but both lead to avoidance when presented together with positive emotions (Paulus & Wentura, 2016). Accordingly, studies on how processing of threatening emotions can influence people's behavioural responses have produced mixed results.

2.2.2 Spatial navigation and emotional body expressions

As with faces, a similar line of reasoning may apply to another means of human emotional expression such as the body. Body movements and postures can convey emotion-specific information as well (Dael et al., 2012; Witkower & Tracy, 2019; Calbi et al., 2020). Indeed, in everyday life, both facial and bodily emotional expressions serve as channels for conveying emotional information. For example, when people experience sadness, they often show corresponding bodily expressions, such as lowering their head, while happiness is often expressed through bodily gestures, such as dancing in joy (de Gelder, 2006). Emotional body expressions can serve a variety of functions, such as expressing happiness, indicating danger, alerting us to a threat in our environment, or communicating a threatening or aggressive message to others. Typical fear behaviours, such as putting one's hands over one's face and running for cover, send strong signals of fear to observers who may not be aware of the danger themselves. Conversely, anger can be reflected in physical expressions such as clenched fists and stomping, in addition to angry facial expressions (Proverbio et al., 2018). Emotions conveyed through the body seem to be recognised across cultures (Witkower et al., 2021). In contrast to facial expressions, some researchers have argued that bodily expressions may be a more reliable indicator of genuine emotions because individuals can hide their true feelings through deceptive facial expressions, such as insincere smiling, while it may be more difficult to hide their bodily expressiveness (Van den Stock et al., 2007). In addition, body expressions may compensate for emotional information missing from facial expressions When using ambiguous facial expressions, bodily expressions played a more important role than facial expressions in shaping the perceived affective valence of intense expressions (Aviezer et al., 2012a). Results from an eye movement experiment also showed that when the emotion of facial expressions was incongruent with that of bodily expressions, the fixation pattern was influenced by the emotional body(Aviezer et al., 2008).

Regarding the distinction between fear and anger, neuroimaging research has shown that key brain regions involved in emotion processing are particularly responsive to fearful and angry body language (e.g., amygdala), sometimes even more so than to faces, and that brain area activations are emotion specific (de Gelder et al., 2004; Hadjikhani & de Gelder, 2003; Grèzes, 2007; Pichon et al., 2009). Van Heijnsbergen, Meeren, Grèzes and de Gelder (2007) provided experimental evidence for a rapid neural mechanism for the perceptual processing of fear signals expressed by the body, suggesting that fearful body expressions are encoded in early stages of visual processing, similar to fear in faces. Indeed, fearful bodies are categorised as such faster than neutral and happy bodies are categorised as neutral or happy, respectively (and faster than emotional scenes, Botta et al., 2021). However, bodies expressing anger are more easily recognised than bodies expressing fear, happiness, or despair, even when only individual body parts are shown (e.g., an arm, Visch et al., 2013).

Compared to faces, body posture not only conveys emotional information, but also provides essential cues for movement and action (Poyo Solanas et al., 2020). Viewing fearful bodies induces a rapid suppression of motor readiness in the observer's motor cortex, which appears to be related to the behavioural inhibition system (Borgomaneri et al., 2015, 2017; similar to faces, Choi & Cho, 2020). Similarly, angry bodies increased motor corticospinal excitability (Hortensius et al., 2016). This suggests an inherent link between emotion perception from bodies and action systems, indicating an influence on motor responses in the presence of threat-related cues. Another study using both faces and bodies in a motor response task that required tapping a screen in response to emotional stimuli found no difference in response times when stimuli were fearful or neutral, but a faster response occurred when angry faces or bodies were presented compared to neutral ones (de Valk et al., 2015).

Beyond facial expressions, the study of emotions expressed through body language provides a richer context. In the case of fear expressed through body cues, research by Öhman (1986) investigated the rapid detection of evolutionarily relevant fear stimuli, finding increased vigilance and faster reaction times. Furthermore, research investigating emotional expression through bodies with blurred faces found that bodies alone also carry emotional meaning (for a review see De Gelder et al., 2015). Roelofs, Hagenaars, and Stins (2010) found that viewing angry or fearful facial expressions resulted in increased avoidance tendencies, as measured by backward movements, compared to neutral expressions. This suggests that emotional expressions may elicit automatic approach-avoidance responses. However, research by Riskind et al. (2013) showed that perceiving bodily expressions of fear resulted in faster avoidance movements, whereas perceiving expressions of anger resulted in slower approach movements. These findings suggest that the specific emotions expressed by bodies can influence motor responses related to approach and avoidance behaviours. Neuroimaging studies, such as that conducted by Azevedo et al. (2013), have identified neural correlates associated with approach-avoidance tendencies in response to emotional body expressions. They found activation in brain regions involved in processing emotional stimuli and motor planning when participants viewed bodies expressing fear or anger, suggesting an interaction between emotional perception and action preparation. Finally, Tamietto et al. (2009) showed that the perception of fearful body expressions, particularly when paired with direct gaze, can signal potential social threat and elicit avoidance behaviour. This supports the idea that emotional body expressions, similar to faces, play a crucial role in social signalling and behaviour regulation.

Understanding emotions conveyed by facial and bodily expressions has been extensively studied, with electroencephalographic (ERP) studies providing insights into neural processes. In Meeren et al.'s (2005) research, bodily expressions elicited the P1 component - an early positive response in bilateral occipital electrodes, together with facial expressions. Beyond P1, the N170 component is crucial for discriminating between faces and objects, with body induced N170 showing a less pronounced amplitude than facial expressions. In terms of temporal aspects, Borhani et al. (2015) found that N170 latency was significantly delayed for body expressions compared to facial expressions, leading to its designation as N190. However, conflicting conclusions remain regarding whether the N170 consistently reflects emotional content (Ashley et al., 2004; Rellecke et al., 2012). When examining late positive potential (LPP) components, such as the P300 or P3, and the subsequent slow wave (PSW), these reflect high-level cognitive processing during tasks such as attention and discrimination. Gu et al. (2013) proposed a three-stage model of facial and bodily expression processing using ERPs, highlighting automatic threat extraction from bodily expressions in the first stage, detection of inconsistencies between facial and bodily expressions in the second stage, and integration and refinement of processing judgments in the third stage. Providing additional behavioural insights, Poyo Solanas et al. (2020) highlighted that body posture conveys emotional information and essential movement cues. These findings highlight complex neural processing mechanisms and reveal overlaps and potential interactions between body and facial expressions (Zhu & Luo, 2012; Hietanen et al., 2014; Borgomaneri et al., 2015; Borhani et al., 2016). Therefore, as with faces, bodily expressions seem to influence human responses, and the evidence for the distinction between anger and fear in such responses is rather mixed. Furthermore, to the best of our knowledge, no study has used such stimuli in spatial or navigation tasks, so further research is needed.

2.2.3 Do non-social emotional stimuli affect navigation?

Emotions can be expressed through behaviours such as facial expressions, body language and vocal cues. These can be defined as types of social stimulus, i.e. emotions communicated by a person's face or body. In general, people respond to others' emotions because, as we have summarised, they communicate social actions (e.g., Gonzalez-Garrido et al., 2013). However, emotional information can also be induced in the observer by means of the context surrounding the observer. Research has shown that the environment has a significant impact on emotional responses. Serene natural environments can evoke calm and happiness, whereas busy urban environments can lead to stress and anxiety (Ulrich, 1983). Similarly, pleasant, bright and open spaces do not evoke fear, whereas dark and confined spaces can evoke similar responses. Research suggests that certain environments can trigger stress responses, while others can aid in stress recovery and alleviate attentional fatigue (Kaplan, 1995). Hartig (2011) suggested that exposure to restorative environmental images might improve navigational skills by supporting recovery from attentional fatigue. Indeed, stressful images might also impair navigational skills and require more directed attention (Nori et al., 2023).

Although we are not aware of any studies based on such exposure to positive and negative environmental scenes, there is evidence that emotional non-social cues can influence spatial memory. Ruotolo et al. (2019) found that the location of positive landmarks is remembered more accurately than the location of neutral and negative landmarks, but routes with negative landmarks are remembered as having taken longer to travel than those with the other landmarks. Palmiero (2017) found that topographical memory was enhanced by both positive and negative emotional landmarks, but positive landmarks were found to be more effective for allocentric memory. Piccardi et al (2020), moreover, found that people using negative emotional landmarks performed the worst in navigation tasks. Therefore, it may be that emotions evoked by non-social stimuli, such as the environmental context, also influence wayfinding in realistic environments, although research has mostly focused on landmark-based tasks. However, one reason why exposure to contextual scenarios might not be sufficient to influence wayfinding is that the stimuli might not stimulate behavioural reactions as much as socio-emotional stimuli. Therefore, in the absence of a facial or social and emotional informative cue, information with only contextual emotional valence and without any subject might not be sufficient to affect wayfinding behaviors (Dalton et al., 2018). Given the lack in research addressing the role of varying environmental scenes in modulating navigation behaviour, we brought initial evidence to fill such a gap.

2.2.4 Neural Overlaps in Spatial Navigation and Emotion Processing

Numerous brain regions are intricately involved in both emotional and spatial cognition. They collaborate collaborate extensively to integrate emotional and spatial information, thereby facilitating adaptive behavior in response to a diverse array of stimuli. For instance, the amygdala, recognized for its pivotal role in emotional processing such as fear and anxiety, also contributes significantly to spatial memory and navigation (Phelps & LeDoux, 2005). The hippocampus, traditionally associated with spatial navigation and memory formation, is actively involved in encoding and retrieving emotional memories as well (Bannerman et al., 2004; Fanselow & Dong, 2010). The prefrontal cortex, responsible for emotional regulation and executive functions, also participates in spatial cognition, including processes related to spatial working memory. The insular cortex, crucial for emotional processing and subjective emotional experience, also plays a significant role in spatial awareness and navigation (Rosenkranz et al., 2003). Lastly, the cingulate cortex, implicated in emotional regulation, contributes to attentional processes relevant to spatial tasks (Vogt, 2005).

2.2.5 Gender Difference in Spatial Navigation and Emotion Processing

Gender differences in the interplay between spatial navigation and emotion processing have received considerable attention in cognitive psychology and neuroscience, influenced by a range of factors including biological differences, environmental influences and cultural norms (Driscoll et al., 2005; Perssons et al., 2013; Baenninger & Newcombe, 1989; Webley, 1981). Males exhibit superior wayfinding skills compared to females (Coluccia & Louse, 2004; Clint et al., 2012). Males typically outperform females in spatial navigation tasks, which has been attributed to their use of survey spatial strategies and exploration methods (Munion, 2019; Coluccia & Louse, 2004). However, this advantage may not consistently translate into greater efficiency (Lin et al., 2019). Gender differences in navigation extend to virtual environments, with differences in the use of global and local landmark information (Lin et al., 2019). Furthermore, males demonstrate proficiency in both large- and small-scale spatial skills, with greater accuracy in recognising spatial elements (Yuan, 2019; Kim, 2007). Litvak and colleagues (2012) investigated the effect of emotional landmarks on navigation and found that neither males nor females showed differential use of positive or negative landmarks. However, females showed superior navigational efficiency when exposed to negative landmarks in a virtual reality maze environment, while males showed no significant difference in performance based on the emotional valence of landmarks.

In particular, potential factors contributing to gender differences in spatial navigation include biological differences, such as right hemisphere dominance and higher levels of testosterone in males (Driscoll et al., 2005; Perssons et al., 2013), as well as environmental influences, such as the amount of time spent playing video games with a strong spatial component (Baenninger & Newcombe, 1989). In addition, cultural environments may provide different opportunities for exploration, which may exacerbate gender differences (Webley, 1981). A combination of these factors may exacerbate differences in spatial and navigational skills (Casey, 1996; Clements et al., 2006; Voyer et al., 2006).

Gender differences have also been observed in emotion processing, with recent evidence revealing inconsistencies in facial expression recognition abilities between genders (Fischer et al., 2018). Males may rate emotional body expressions as more arousing and show stronger behavioural responses to threatening cues than females, possibly influenced by different motor tendencies (He et al., 2018; Han, 2008; Kret & de Gelder, 2012). Females may be better at recognising facial expressions, even when they are subtly expressed (Hoffman et al., 2010), whereas males show stronger behavioural responses to threatening cues (Kret & de Gelder, 2012; Montagne et al., 2005; Han, 2008). Socialisation processes and innate temperamental differences also might contribute to these differences (Brody, 1985). Males may experience more intense emotions while females express emotions more openly, especially negative ones (Deng et al., 2016). Spatial anxiety, which significantly affects navigation, may also differ between the genders, with females showing higher spatial anxiety than males (Lawton, 1994; Coluccia & Louse, 2004). Males may also be more sensitive to threatening environmental scenes than females, as indicated by greater amygdala activation when exposed to such stimuli (Schienle et al., 2005).

Research highlights neural substrates and brain lateralisation differences between the genders in basic functions such as visuospatial skills and emotion processing (Yuan et al., 2019; Gonzalez-Garrido et al., 2015). Males typically show right hemisphere dominance for spatial navigation and negative facial expression recognition, whereas females show right lateralisation for spatial perception and bilateral activations for face processing (Clements et al., 2006; Jacobs et al., 2010; Kolb & Taylor, 2000; Proverbio et al., 2006; Rilea, 2008; Persson et al., 2013).

Hemispheric lateralisation also plays a role, with males showing right lateralised activation in the hippocampus during navigation tasks, which may contribute to their superior direction estimation (Persson, 2013). However, task complexity, familiarity with the environment and cognitive ability also influence gender differences in spatial behaviour (Goede, 2009). As both processes have a dominant right lateralisation in males, these mechanisms may interfere when pitted against each other, leading to performance impairments (Hartikainen et al., 2000; Persson, 2013).

2.2.6 Advanced Tools: Virtual Reality

Spatial cognition and wayfinding have traditionally been studied through field studies, laboratory experiments and surveys. Field studies, such as Golledge's (1999) observational research, focus on real urban environments and the role of landmarks in navigation. Laboratory experiments, such as Tversky and Lee's (1998), use controlled settings to investigate how individuals mentally represent and recall spatial information, while surveys and questionnaires, such as Thorndyke and Hayes-Roth's (1982), collect self-reported data on individuals' perceptions and experiences related to spatial cognition. Virtual reality (VR), on the other hand, delivers immersive experiences through sophisticated software and hardware, providing users with lifelike visual, auditory and sometimes tactile sensations (Slater & Sanchez-Vives, 2016) and could be used to assess spatial navigation. It is a transformative technology that immerses users in simulated environments, in contrast to augmented reality (AR), which overlays digital elements onto the real world (Papagiannis, 2017). VR offers unparalleled spatial visualisation, providing experiences that feel extremely real enhancing entertainment and exploration (Slater & Sanchez-Vives, 2016). In research, education and training, it facilitates learning by allowing learners to practice skills and explore scenarios in a safe, controlled environment (Huang et al., 2010). Medical professionals use VR for training, surgical planning and patient education, simulating surgeries and medical procedures to improve understanding and skills (Kneebone, 2003). Architects and designers use VR for architectural visualisation, allowing clients to virtually navigate through structures prior to construction (Bertol, 1996). In gaming, VR provides unprecedented immersion, enhancing spatial awareness and navigation skills through physically interactive gameplay (Ryan, 1999). In spatial navigation studies, despite the lack of some sensory information, performance in virtual tasks is comparable to performance in the real world (Aubin et al., 2018; Coutrot et al., 2019; Cushman et al., 2008; Kalová et al., 2005). Specifically, the acquisition of spatial knowledge can be simulated to resemble the real world in immersive virtual reality (Jeung et al., 2022; Ruddle et al., 1997). VR has also been used to study affective states during navigation by manipulating environmental conditions to induce and study emotional responses (Baños et al., 2012). Witmer et al. (1996) proved the effectiveness of this approach for training real-world navigation, simulating complex scenarios, and modelling real-world environments. However, VR also presents significant challenges. Cost and accessibility remain notable barriers to widespread adoption, with high-quality equipment often being prohibitively expensive (Botelho, 2021). Additionally, some users experience motion sickness, which causes discomfort or dizziness due to discrepancies between visual cues and physical movement (Chang et al., 2020; Conner et al., 2022). Prolonged use of VR can cause eye strain, fatigue, and posture problems, which raises concerns about potential health implications (Nichols & Patel, 2002). Also, it may lead to social disconnection and reduced awareness of the physical environment due to isolation from reality (Slater & Wilbur, 1997). Ethical considerations arise from VR's ability to create realistic and potentially distressing scenarios, which require careful handling by researchers (Madary & Metzinger, 2016). Indeed, VR represents an advanced technique that, if properly employed, can increase the quality of research.

2.2.7 The Present Research

In the present research, we immersed participants in a simulated environment, which represents a moderately ecological way of investigating wayfinding behaviour. Virtual reality (VR) can be crucial in assessing wayfinding performance (Jeung et al., 2022) due to its ability to replicate immersive environments, facilitate natural movements, and allow navigation with an enhanced sense of presence that provides an almost natural field of view. In three experiments, participants were introduced to a wayfinding task in a VR environment (i.e., a multi-storey office building), which consisted of first finding an object in the environment (i.e., encoding phase, T1) and then finding the same object in the same location (i.e., recalling phase, T2). Between the two phases, emotional cues were presented in a task unrelated to wayfinding (i.e., categorising cues into relevant categories). We measured travel times and distances travelled at T1 and T2 as behavioural outcomes related to participants' navigational performance (i.e., Burke, Kandler, & Good, 2012; Dong et al., 2022). We also investigated whether there were any differences due to emotional conditions and gender.

Our principal research question was whether exposure to emotional stimuli could facilitate or limit navigational performance during a wayfinding task. In Experiment 1, we used male and female faces expressing fear, anger, or neutral expressions. In Experiment 2, we used male and female bodies expressing the same types of emotions (with blurred faces) to extend the results of Experiment 1 to a new type of social stimulus. In Experiment 3, we used threatening or reassuring scenes to test whether non-social stimuli can influence navigation performance in the same way as social stimuli.

First, we expected participants to show faster travel times and shorter distances travelled in the recall phase than in the encoding phase due to learning and familiarity in the second exploration after the first one (Hp1). Second, based on our review of the available research, we expected that exposure to a threatening emotional stimulus might interfere with wayfinding performance (Hp2). Threatening cues might influence the behavioural tendencies of participants asked to navigate an environment, potentially moderating the outcome of wayfinding performances. However, due to the novelty of our investigation, it was not possible to precisely hypothesise the direction of the effect, i.e. whether threatening cues improve or impair wayfinding performance. Furthermore, and specifically for Experiments 1 and 2, it was not possible to hypothesise whether fear or anger would differ in their effects. We compared their effects and provided a possible explanation for the pattern of results in the Discussion section. In all cases, gender differences were expected to modulate spatial navigation and the effect of emotion processing on it, because of their strong influence on these two domains. In all of our studies, we assumed that emotion could influence the subsequent recall phase, even when participants were not explicitly instructed to focus on such stimuli during the primary wayfinding task. There is evidence that threatening stimuli can influence the allocation of attentional resources even when they are not presented as an essential component of cognitive and behavioural tasks (Paulus & Wentura, 2016; Zsidó et al., 2022, 2023), especially in situations of high cognitive demand (Pessoa et al., 2012).

Overall, we based our assumptions on the possibility that such stimuli can influence task outcomes even when participants are not directly expected to attend to the emotion expressed by the faces and bodies or conveyed by the scenes (Berggren & Derakashan, 2013; Chen & Bargh, 1999; Celeghin et al., 2020; O'Toole et al, 2011; Paulus & Wentura, 2016; Pessoa, 2009; Ricciardelli et al., 2012; Zsidó et al., 2023). However, it is worth noting that there are contrasting findings in this regard (Berger, Richards, & Davelaar, 2017; Mancini, 2020, 2022; Mirabella et al., 2023; see also the Discussion section). All data and analysis scripts are available at https://osf.io/7u8vx/.

2.2 EXPERIMENT 1: Effect of Negative Facial Expressions on Wayfinding in VR

In a VR environment, participants were introduced to a wayfinding task, which consisted of first finding an object located in the environment (i.e., encoding phase, T1) and then finding the same object at the same location (i.e., recalling phase, T2). Emotional faces showing fearful, angry, or neutral expressions were shown between the two phases in a task unrelated to wayfinding (i.e., a gender categorisation). We measured travel times and distances travelled at T1 and T2 as behavioural outcomes related to participants' navigation performance (i.e., Burke et al., 2012; Dong et al., 2022) and inspected whether any differences were due to emotional conditions and gender.[2]

2.2.1 Methods

We employed a 3 (emotion: neutral vs fearful vs angry faces) x 2 (time: encoding vs recalling) x 2 (gender: female vs male) mixed subjects design, with gender as a between-subjects factor. In Experiment 1, all participants were exposed to the three emotional conditions in sequence, as the emotional condition was a within-subject factor. Gender was the only between-subjects factor.

2.2.1.1 Participants

For the present study we collected a sample of 58 healthy student participants using the university recruitment website and snowball sampling[3]. Data collection took place in part during the Covid-19 restrictions in Italy (2020-21). Since we could not base our sample estimation on a known target effect size, due to the novelty of the design, we did not run a priori power analysis and collected participants for 6 months. We limited the age to a range between 18 and 40 years to avoid the natural decline in navigation functionality and limit the side effects of cybersickness (Lithfous et al., 2014; Diersch & Wolbers, 2019). Participants with vision disparities not corrected to normal vision, suffering from neurological conditions (e.g., epilepsy), and/or sea/car sickness, who might be sensitive to virtual reality side effects, were not included in the study. Three participants dropped out during the experiment due to cybersickness and were excluded from the analysis. Our final sample consisted of 55 participants (24 males, M_{age} = 23.5, SD_{age} = 2.72; 31 females, M_{age}= 21.5, SD_{age} = 2.55). We ran a sensitivity power analysis which showed that our study could detect a minimal effect of η^2_p = .08 (Cohen's f = .30) with this sample size, and power = .80 at α = .05.

The study was approved by the Committee for Research Evaluation (CRIP) of the Department of Psychology of the University of Milan-Bicocca (RM 2020-366). All participants received written informed consent and were treated in accordance with the Declaration of Helsinki. Participants received university credits in exchange for their participation.

2.2.1.2 Materials

Apparatus: Oculus Rift S was utilized to project the entire experiment to the participants (Figure 2.1). The head-mounted device featured a 1,280 × 1,440 LCD with an 80 Hz refresh rate and a field of view measuring 86° x 86°. During navigation sessions, participants had autonomous control over their movements using two controllers. For the navigational task, a customized "office building" consisting of four floors was created (see Figure 2.2). Floor 0 was used for training, while Floors 1, 2, and 3 were used for testing.

[2] This experiment was published as Mohamed Aly et al. (2024).

[3] We also ran an identical pilot study (N=20, see Appendix).

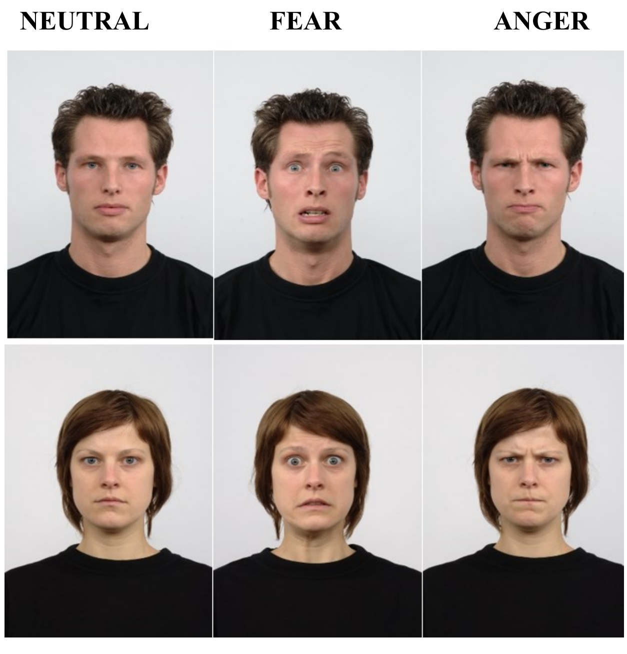
Figure 2.1. Oculus Rift S

Figure 2.2 Images of the Office Building Asset created in Unity.

The mazes within the environment were designed and configured using the Unity cross-platform game engine. Each floor contained various barriers within an enclosed arena, with no written indications. Distinct pieces of furniture served as landmarks or reference points for participants, which were repeated on each floor. Stair access and elevator usage was not permitted. Participants had a standard speed of 2 "unity meters" per second, but they could adjust their speed by -/+ 0.5 meters using the controller's buttons. This setup allowed participants to choose their preferred speed at all stages and mitigate cybersickness. For each condition (three in total), the encoding phase and the recalling phase took place on the same floor to ensure comparable performances before and after the exposure to emotional stimuli. Therefore, each participant entered each floor twice for being exposed once to each of the three emotional expressions. The starting point and target object were always in the same position on each floor but differed between floors. The order of floor presentation and assignment of emotional conditions were counterbalanced. Additionally, slight variations in the maps of the floors were introduced to avoid repetition of the map conformation (see below the test of maps' heterogeneity). Following Nazareth and Newcombe (2019) coding scheme our wayfinding task has the following features: environment: indoor (office); testing medium: VR (Oculus Rift-S); route perspective: route (first-person walking, no teleportation); route selection: free choice-not taught; timing conditions: limited (10 minutes maximum per session); cues: proximal (non-interactive landmarks); familiarity: learned; feedback: immediate (target location found in each trial); hints: no helping provided; device assistance: not present; learning interval: immediate (testing begins after manipulation); outcome measures: times and distances (seconds and Unity's meter unities).

Stimuli. The faces used for the emotion categorization task were selected from the Radboud Faces Database (Langner et al., 2010). The dataset consisted of 15 female and 15 male frontal faces expressing neutral, fearful, or angry expressions (see Figure 2.3).

Figure 2.3. Examples of male and female expressing fearful, angry, and neutral faces extracted from the Radboud Face Database (Langner et al., 2010). The list of stimuli id used extracted from the database are available on OSF https://osf.io/wzbvy/. See Radboud Faces Database (ru.nl) to have access to the database. Two examples were reproduced below with permission by the authors.



2.2.1.3 Procedure

Participants were introduced to the laboratory, signed the informed consent, and received formal instructions about the experimental phases: training, encoding, categorization, and recalling (see Figure 2.5 for a schematic procedure).

Training. We asked participants to put on the Oculus Rift HMD and enter the practice floor for five minutes to familiarize themselves with the setting, the task, and the target object (i.e., blue box). Habituation to the tool was intended to reduce predictable cybersickness symptoms (e.g., headache, blurred vision, motion sickness, nausea). The training floor differed from those used in the testing so as not to affect the main task's results. At the end of the training, participants began the experimental phases, which were two (encode vs recall) for each of the three emotional conditions.

Encoding Phase. Participants entered a new floor randomly picked among a set of three (counterbalanced between subjects) and were instructed to explore the environment to find the target object, always a blue box. We reminded them to pay attention to the surroundings and remember the route taken to get to the object. Once they found the object, they started the next phase.

Categorization Task. Within the same virtual setting and after a short break time, participants entered a grey-walled bright room. They were asked to take part in a categorization task based on face stimuli. Instructions told them to make the responses using the controller's buttons at they own pace. We told them to take their time in answering because the main goal of the procedure was the prolonged exposure to the emotional stimuli. During such task they were shown a series of face pictures projected on the wall in front of them. The faces' dimensions were kept as close as possible to those seen on a PC monitor with a viewing distance of about 50 cm. The faces expressed neutral or fearful or angry emotions, depending on the conditions, which were counterbalanced between-participants. The face stimuli were repeated twice in random order per task (60 stimuli in total). The sequence of event in a trial was as follows: a fixation cross for 1000 msec; the emotional face for 1000 msec; a mask for 500 msec; a question asking, "Male [Female] or Female [Male]?" with labels and button responses counterbalanced between participants. At the end of the trial, we allowed a maximum response time of 3000 msec. The task lasted on average circa 5 minutes (Figure 2.4).

Recalling Phase. Participants immediately returned to the same floor of the encoding phase to test their ability to find again the box, which was placed in the same location of the encoding phase.

Questionnaires. We also measured exploratory variables whose descriptive results are reported in Appendix 3. Finally, participants were thanked and debriefed.

Figure 2.4. Example of the sequence of events in a trial for the categorization task.

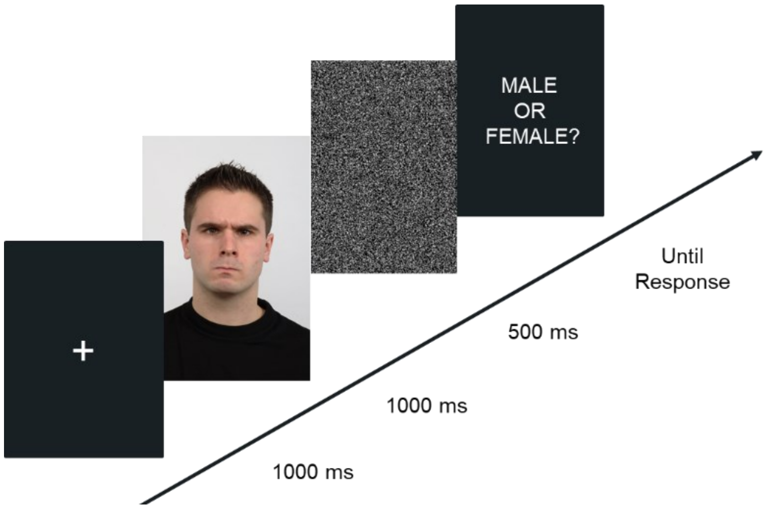
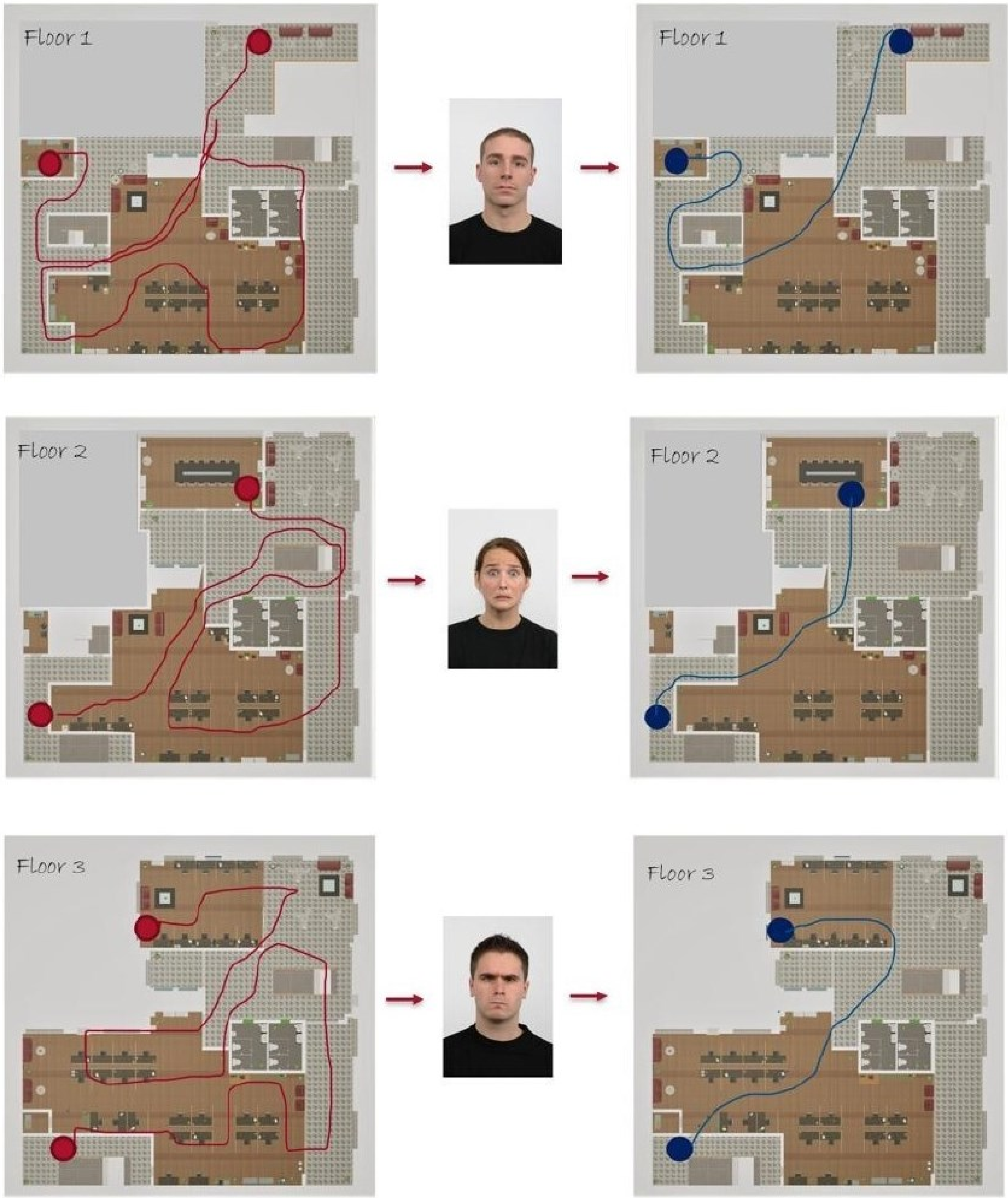


Figure 2.5. Example of the procedural sequence with footprints. Encoding phases are shown on the left, the categorization task in the middle, and the recalling phases on the right.

ENCODING PHASE **CATEGORIZATION TASK** **RECALLING PHASE**



2.2.1.5 Data Preparation and Statistical Analyses

As dependent variables, we recorded travel times in milliseconds from the moment they entered each floor until they reached the target object. Moreover, we measured the distances travelled from the first step until reaching the object using a Euclidean formula for calculating the distance between one temporally ordered position and the following one, then we summed the results. The latter scores were based on participants' x and z coordinates on the floor registered five times per second. The distances are expressed with an internal Unity's unit of measure (um). For both travel times and distance travelled we created average scores for each experimental phase. Analyses were carried out by means of Jamovi (2023) and R Studio (2021).

For the analyses, we first checked whether our data respected the assumptions of parametric tests. For testing the normality of errors, we inspected the QQ-plot of the fitted models' residuals. For the homogeneity of variance, we conducted Leven's tests. For the sphericity assumption, we conducted Mauchly's tests. For both the dependent variables, the assumptions were not respected (See Appendix 2). Therefore, we applied a logarithmic transformation to the two dependent variables to obtain pseudo-normal data (Marmolejo-Ramos et al., 2015). The transformation shifted and centralized the extremities, reducing the impact of extreme observations. After transformation, the assumptions were not violated anymore. Hence, we proceed with conducting mixed ANOVAs.

For sake of simplicity and to highlight the differences between the three emotional conditions, for each analysis examining the interactions between emotion and time (i.e., two-way interaction), and between these factors and gender (i.e., three-way interaction), we calculated a differential score by subtracting Time 2 performance from Time 1 (T1-T2) within each emotional condition. The higher the score, the better the performances at T2 compared to T1. Simple effects analyses were adjusted with the Bonferroni-Holm method. We reported effect sizes (η^2_p for the F tests, Cohen's d for the t tests) along with the statistical tests (d are reported in absolute value for easier interpretation). We also made preliminary analyses to test whether the travel time and the distance travelled on each floor was balanced and not dependent on the heterogeneity of the floor maps. A repeated-measures ANOVA comparing the three floors performed on T1 only – as the emotional exposure had not yet been delivered – showed that the three maps produced no differences in time spent in each floor, $F(2,106) = .57$, $p = .56$, $\eta^2_p = .011$ (Floor 1: $M = 4.56$, $SD = .59$; Floor 2: $M = 4.49$, $SD = .67$; Floor 3: $M = 4.59$, $SD = .59$, see Table 1). While the main effect of gender was significant, $F(1,53) = 19.0$, $p < .001$, $\eta^2_p = .26$, as males spend on average less time on each floor than females, the interaction between maps and gender was non-significant, $F(2,106) = .23$, $p = .79$, $\eta^2_p = .004$. The same analysis made on distance travelled showed no differences between floors, $F(2,106) = .67$, $p = .52$, $\eta^2_p = .012$ (Floor 1: $M = 4.87$, $SD = .48$; Floor 2: $M = 4.78$, $SD = .51$; Floor 3: $M = 4.80$, $SD = .05$; see Table 1). The main effect of gender was again significant, $F(1,53) = 7.09$, $p = .01$, $\eta^2_p = .12$, while the interaction between maps and gender was non-significant, $F(2,106) = .58$, $p = .56$, $\eta^2_p = .01$. Therefore, we can conclude that maps were homogenous in their times and distances travelled.

Table 2.1 . Means and standard deviations (in parenthesis) of travel time and distance travelled in seconds after the logarithmic transformation at T1, before emotional exposure, as a function of the gender.

Map	*Travel Time*		*Distance Travelled*	
	Female	Male	Female	Male
Floor 1	4.77 (0.56)	4.28 (0.51)	4.95 (.46)	4.78 (.50)
Floor 2	4.73 (0.59)	4.19 (0.65)	4.93 (.45)	4.60 (.54)
Floor 3	4.76 (0.56)	4.36 (0.55)	4.86 (.51)	4.71 (.51)

2.2.3 Results

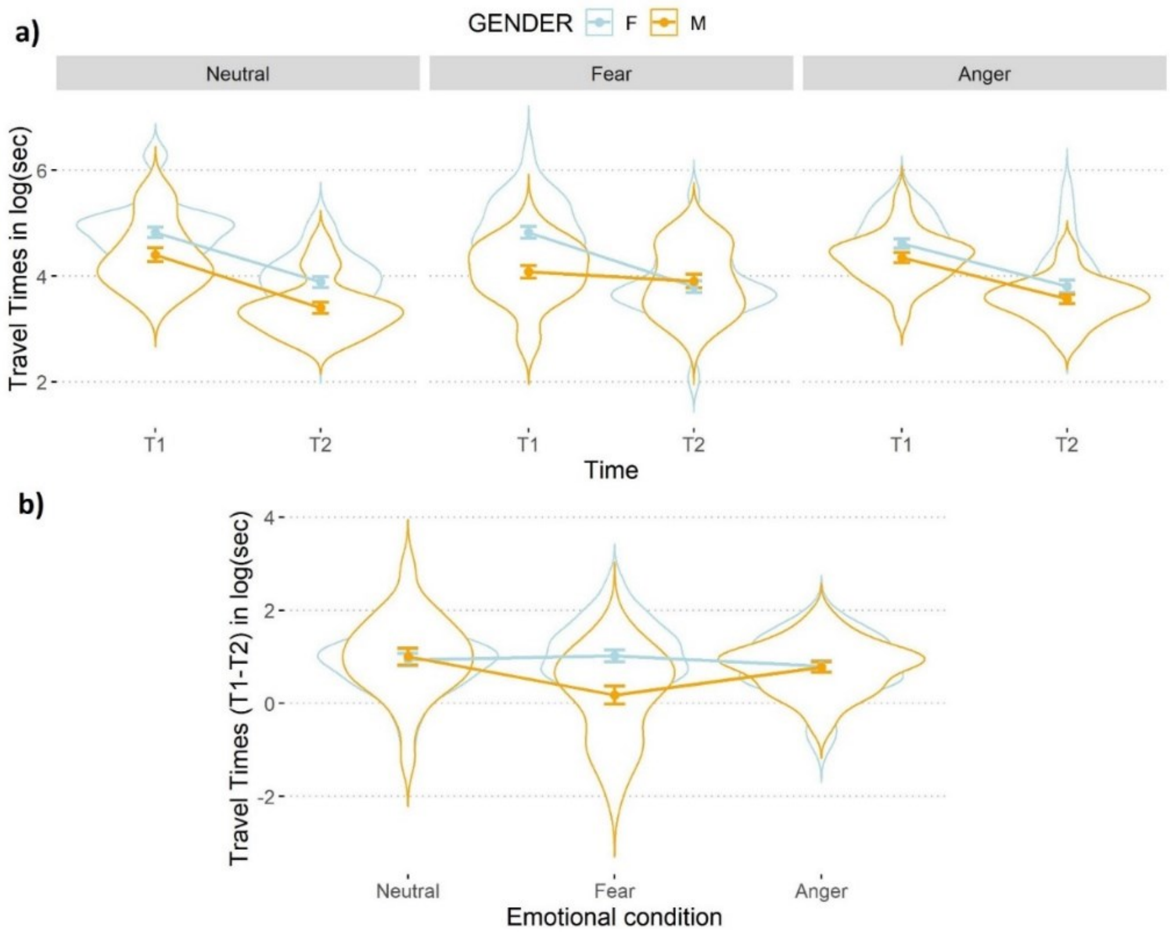
2.2.3.1 Analysis of Travel Time

To determine whether participants' performances were affected by the emotions presented in the emotional conditions, we performed a 3 (emotion: neutral vs fearful vs angry faces) x 2 (gender: female vs male) x 2 (time: T1 vs T2) mixed ANOVA on travel times. Means and standard deviations are reported in Table 2.2. The results showed a significant main effect of time, $F(1,53) = 167.06$, $p < .001$, $\eta^2_p = .77$, such that participants were faster at T2 than T1 showing that they learned the route and recalled it effectively, and a significant main effect of gender, $F(1,53) = 15.4$, $p < .001$, $\eta^2_p = .22$, with males on average being faster than females in reaching the object. The main effect of emotion was not significant, $F(2,106) = .55$, $p = .58$, $\eta^2_p = .01$, as well as the interaction between gender and emotions, $F(2,106) = 1.10$, $p = .34$, $\eta^2_p = .02$. The interaction between gender and time was significant, $F(1,53) = 4.88$, $p = .03$, $\eta^2_p = .08$. A simple effects analysis showed that, while at T1 males were faster than females, $t(94.7) = 4.47$, p < .001, $d = .46$, the difference with females was reduced at T2, $t(94.7) = 1.95$, $p = .05$, $d = .20$. Importantly, the interaction between emotion and time was significant, $F(2,106) = 3.37$, $p = .04$, $\eta^2_p = .04$. Decomposing the interaction revealed that there was no difference in times between the three emotions at T1, $t(211) < |1.63|$, *p*s > .31, $d < .11$, and at T2, $t(211) < |2.16|$, *p*s > .09, $d < .15$. However, this interaction is better inspected with a simple effects analysis on the differential score (T1-T2) within each emotion condition, which showed that participants were slower at T2 compared to T1 after the fearful condition compared to the neutral one, $t(106) = -2.59$, $p = .03$, $d = .25$, while no other comparisons were significant, $t(106) < 1.35$, $p > .36$, $d < .13$. The three-way interaction between emotions, time, and gender was also significant, $F(2,106) = 6.12$, $p = .003$, $\eta^2_p = .10$ (see Figure 2.6). Participants improved their performances from T1 to T2 in all conditions, $t(159) < 7.53$, $p < .001$, $d < .60$, except for males who did not exhibit any improvement after being exposed to the fearful condition reflected in a non-significant difference between T1 and T2, $t(159) = 1.14$, $p = .25$, $d = .09$. At T1, a simple effects analysis on females showed no differences between the three emotional conditions, $t(211) < 1.79$, *p*s > .50, $d < .09$. The same was the case with males, $t(211) < 1.79$, *p*s > .09, $d < .16$, showing that baseline performances were balanced between emotional conditions. At T2, females did not perform differently according to the emotional conditions, $t(211) < |.31|$, *p*s > .99, $d < .04$. Conversely, at T2 males showed a significant difference between the angry and the fearful conditions, $t(211) = -2.30$, $p = .04$, $d = .16$, as well as between the fearful and the neutral conditions, $t(211) = 3.43$, $p < .002$, $d = .24$. This suggests that males were slower after being exposed to fearful faces than after the other two types of faces. Interestingly, no significant difference was found between the anger and the neutral conditions, $t(211) = 1.13$, $p = .26$, $d = .08$. To better inspect this three-way interaction, we analysed the differential score (T1-T2). For females, the travel times did not differ between the three emotion conditions, $t(106) < |1.14|$, *ps* >. 76, $d < .11$, while males were slower at T2 than T1 after being exposed to fearful compared to angry, $t(106) = 2.80$, $p = .01$, $d = .27$, and to neutral faces, $t(106) = -3.84$, $p < .001$, $d = .37$. In contrast, no difference emerged for males between the anger and neutral conditions, $t(106) = 1.04$, $p = .30$, $d = .10$. The comparison between the two genders within each emotional condition showed that, in the fearful condition, males were significantly slower than females, $t(159) = 4.11$, $p < .001$, $d = .65$. However, no such a difference emerged in the anger, $t(159) = .12$, $p = .89$, $d = .02$, or in the neutral conditions, $t(159) = -.30$, $p = .76$, $d = .05$. Hence, the present results are in line with the conclusion that fear was disrupting males' performance more than the other emotions. Such a result was not mirrored on females whose performance was not influenced by any condition.

Table 2.2 Means and standard deviations (in parenthesis) of travel time in seconds as a function of gender and emotional conditions with and without the logarithmic transformation.

Times (sec)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	148 (112.6)	56.55 (33.4)	91.61 (118.6)	100 (71.6)	34.7 (22.6)	65.4 (78.1)
Fear	152 (108.6)	54.77 (44.5)	97.39 (105.3)	68.3 (35.0)	59.8 (36.8)	8.46 (57.5)
Anger	113 (58.1)	58.55 (56.3)	55.19 (64.3)	86.5 (46.5)	38.6 (17.6)	47.9 (47.0)
Times (log)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	4.82 (.55)	3.88 (.55)	0.93 (.74)	4.40 (.60)	3.40 (.51)	1.00 (.86)
Fear	4.82 (.64)	3.80 (.61)	1.02 (.71)	4.08 (.57)	3.90 (.62)	0.17 (.95)
Anger	4.61 (58.1)	3.81 (.66)	0.80 (.65)	4.34 (.47)	3.56 (.41)	0.77 (.55)

Figure 2.6. Line and violin plots representing the difference in travel times in seconds (after the logarithmic transformation) between single encoding (T1) and recalling (T2) sessions (a) and differential score (T1-T) (b) as a function of gender and emotional conditions. Lower numbers indicate better performances in graph a, and vice versa in graph b. The light blue line represents female participants, and the orange line represents male participants. Bars represent standard error around the means.



2.2.3.2 Analysis of Distance Travelled

We performed a mixed 3 (emotion: neutral faces *vs.* fearful faces *vs.* angry faces) x 2 (gender: female *vs.* male) x 2 (time: T1 *vs.* T2) ANOVA on distance travelled. Means and standard deviations are reported in Table 2.3.

The main effect of time was significant, $F(1,53) = 88.48$, $p < .001$, $\eta^2_p = .62$, indicating that the distances travelled were inferior at T2 than T1. The main effects of gender, $F(1,53) = 1.70$, $p = .20$, $\eta^2_p = .03$, and emotions, $F(1,53) = .73$, $p = .40$, $\eta^2_p < .001$, were not significant. The interaction between time and gender was significant, $F(1,53) = 4.53$, $p = .04$, $\eta^2_p = .08$. A simple effects analysis showed that, while males' travelled distances were shorter than females at T1, $t(106) = 2.42$, $p = .02$, $d = .24$, this difference with females was cancelled out at T2, $t(106) = -.51$, $p = .61$, $d = .05$. The interaction between gender and emotions was not significant, $F(2,106) = 2.00$, $p = .14$, $\eta^2_p = .04$, whereas the interaction between emotions and time was significant, $F(2,106) = 4.44$, $p = .01$, $\eta^2_p = .08$. A simple effects analysis examining the interaction revealed that there was no difference in distance travelled between the three emotions at T1, $t(211) < |1.93|$, *p*s > .16, $d < .13$, and at T2, $t(211) < |2.29|$, *p*s > .07, $d < .16$. In addition, this interaction can be further inspected with a simple effects analysis on the differential score (T1-T2) within each emotional condition showing that participants travelled longer distances at T2 compared to T1 after the fearful condition compared to the neutral one, $t(106) = -2.91$, $p = .01$, $d = .28$, and no other comparisons were significant, $t(106) < 2.01$, *p*s > .09, $d < .20$. As before, a significant interaction between emotions, time, and gender was found, $F(2,106) = 4.32$, $p = .02$, $\eta^2_p = .07$ (see Figure 2.7).

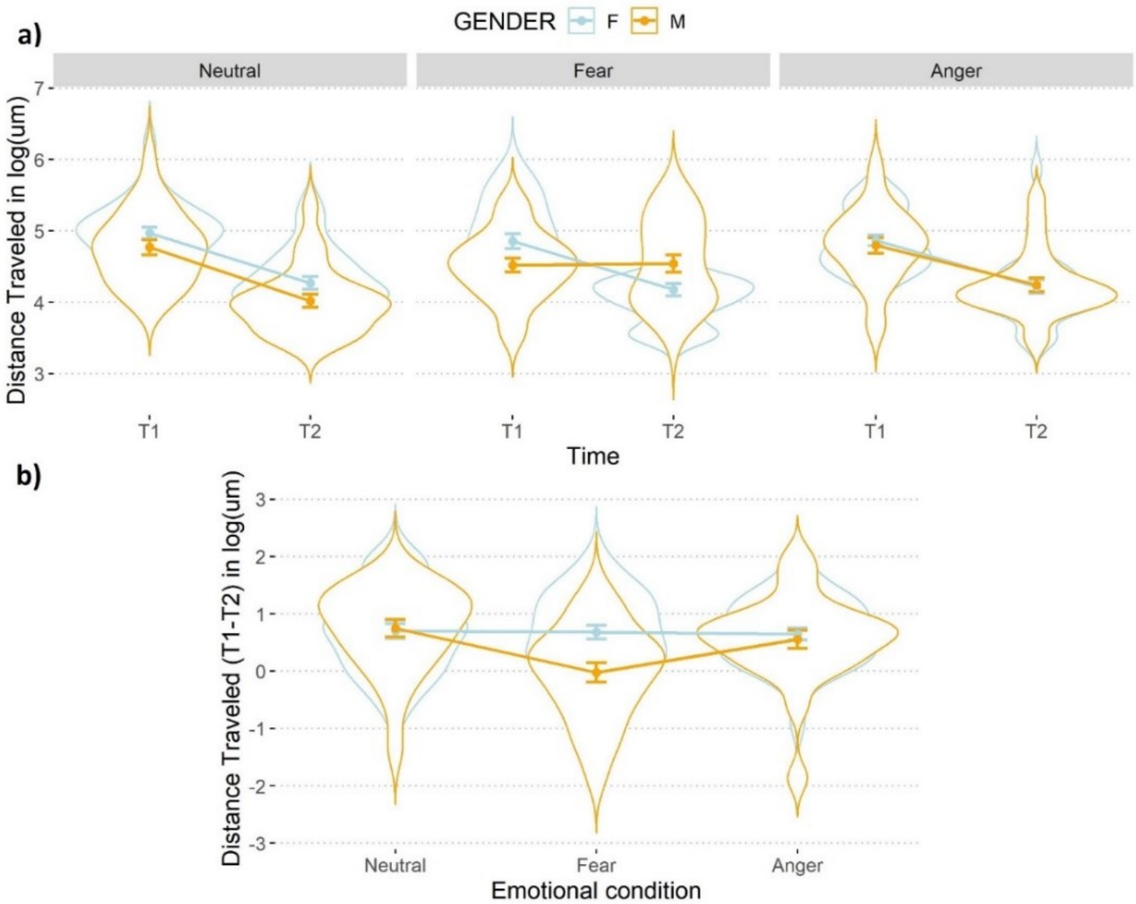
A simple effects analysis on the three-way interaction showed that females and males improved their performances from T1 to T2 in all conditions, $t(159) > 3.78$, *p*s < .001, $d > .30$, but males did not show any difference between distance travelled at T1 and T2 after the fear manipulation, $t(159) = -.15$, $p = .88$, $d = .01$. At T1, a simple effects analysis on females showed no differences between the three emotional conditions, $t(211) < |.91|$, *p*s > .99, $d < .06$, as well as for males, $t(211) < |1.96|$, *p*s > .15, $d < .13$, showing that baseline performances in distance travelled were balanced between emotional conditions. At T2, females did not perform differently following the emotion manipulations, $t(211) < |.76|$, *p*s > .99, $d < .05$. In contrast, at T2 a significant difference between the fearful and the neutral conditions was observed for males, $t(211) = 3.72$, $p < .001$, $d = .26$. This indicates that males travelled longer distances after the fearful condition. However, the difference was not markedly different between the fearful and the angry conditions, $t(211) = -2.15$, $p = .06$, $d = .15$, as well as the angry and the neutral conditions, $t(211) = 1.57$, $p = .12$, $d = .11$.

When looking at the differential scores (T1-T2), the results showed that, for females, distance travelled did not differ between the three emotional conditions, $t(106) < -.27$, *p*s >. 99, $d < .03$, while males travelled longer distances at T2 than T1 after being exposed to fearful compared to angry, $t(106) = 2.83$, $p = .01$, $d = .28$, and to neutral faces, $t(106) = -3.78$, $p < .001$, $d = .37$. No difference emerged between the anger and neutral condition for males, $t(106) = -.95$, $p = .34$, $d = .09$. Moreover, males travelled longer distances than females in the fearful condition, $t(159) = 3.59$, $p <.001$, $d = .57$, but no difference was observed when they were exposed to anger or neutral emotions, $t(159) < .49$, *p*s > .63, $d < .08$.

Table 2.3. Means and standard deviations (in parenthesis) of distance travelled in seconds as a function of gender and emotional conditions with and without the logarithmic transformation.

Distance (um)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	154 (83.2)	81.6 (46.2)	72.9 (99.7)	135 (80.0)	63.1 (39.7)	71.5 (94.9)
Fear	152 (83.7)	75.7 (50.2)	75.9 (91.5)	102 (49.3)	112 (68.1)	-9.70 (91.8)
Anger	114 (61.1)	80.7 (64.5)	63 (72.0)	138 (76.0)	78.4 (47.5)	59.8 (99.8)
Distance (log)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	4.97 (.45)	4.27 (.49)	.69 (.73)	4.77 (.51)	4.02 (.46)	.75 (.75)
Fear	4.86 (.58)	4.18 (.50)	.68 (.66)	4.52 (.47)	4.54 (.60)	-.02 (.83)
Anger	4.87 (.41)	4.22 (.53)	.65 (.59)	4.70 (.53)	4.24 (.46)	.55 (.77)

Figure 2.7. Line and violin plots representing the difference in distance travelled in seconds (after the logarithmic transformation) between single encoding (T1) and recalling (T2) sessions (a) and differential score (T1-T) (b) as a function of gender and emotional conditions. Lower numbers indicate better performances in graph a, and vice versa in graph b. The light blue line represents female participants, and the orange line represents male participants. Bars represent standard error around the means.



2.2.4 Discussion

Consistent with our hypothesis, participants were faster and travelled shorter distances in the recall phase than in the encoding phase. Males were faster and travelled shorter distances on average than females, which may be in line with their greater wayfinding abilities (Coluccia & Louse, 2004). Indeed, in the neutral condition, i.e., without any manipulation of emotion, male's performance was better than females. The hypothesised effect of negative emotions on the navigation performance of all participants was observed but was better explained by a higher-order interaction with gender. In fact, fearful faces only disrupted males' navigation, while this was not the case for females, who were unaffected. Angry and neutral faces had no effect on participants' performance.

2.3 EXPERIMENT 2: Effect of Negative Body Expressions on Wayfinding in VR

In Experiment 1, we found that fearful faces were effective in reducing male participants' wayfinding performance. In this experiment, we investigated whether negative bodily expressions that convey anger or fear could influence individuals' wayfinding abilities in a similar way to faces. In fact, in a similar experiment to the previous one, we used bodies with clear emotional expressions but with blurred faces. To investigate these effects, participants were asked to navigate the same virtual environment. Importantly, participants were intermittently exposed to three emotional conditions consisting of a series of images depicting angry, fearful, and neutral bodily expressions simulated by male and female actors. We also investigated gender differences in the processing and expression of body and facial emotions, as reported in the literature (e.g., He et al., 2018). If emotional bodies exert an influence on wayfinding due to their similarity to emotional faces, we expect to observe a pattern similar to our previous experiment, with males exposed to fearful bodies (vs. angry bodies vs. neutral bodies) showing a more pronounced decline in performance compared to females. Conversely, if emotional bodies prove insufficient to elicit such an effect, we should not observe significant differences between the three emotional conditions.

2.3.1 Method

We employed a 2 (time: time 1 vs. time 2) x 3 (emotional bodies: neutral vs. fear vs. anger) x 2 (gender: male vs. female) mixed design. We measured travel times and distance travelled as dependent variables. Participants were exposed to the three emotional conditions in random sequence; thus, the emotional conditions and times in VR (T1 vs. T2) were within-subject factors and gender was the only between-subjects factor.

2.3.1.1 Participants

Based on Experiment 1's smallest effect found (distance travelled), a priori power analysis suggested a sample of 67 participants to find a three-way interaction effect of $f = .14$ ($\eta^2_p = .07$, power = .80, alpha = .05, MorePower 6.0.1). We applied the same inclusion and exclusion criteria of the previous experiment. We collected participants for 10 months advertising the study on campus and outside. However, we could not reach our target sample size due to time constraints imposed by the present dissertation. Eventually, we stopped data collection at 37 university students (11 males, $M_{age} = 23.7$, $SD_{age} = 3.41$; 26 females, $M_{age} = 21.2$, $SD_{age} = 2.24$). According to a sensitivity power analysis, with this sample size we could observe a minimum effect size of $f = .37$ ($\eta^2_p = .12$) with power = .80 at alpha = .05.

The study was approved by the Committee for Research Evaluation (CRIP) of the Department of Psychology of the University of Milan-Bicocca (RM 2020-366) All participants received written informed consent and were treated in accordance with the Declaration of Helsinki. Participants received university credits in exchange for their participation.

2.3.1.2 Materials

Apparatus. We used the same virtual environments of Experiment 1. This time we employed the Oculus Quest 2 All in One set of virtual headsets that have a 1832x1920 per-eye resolution LCD 80 Hz and a field of view of 93°×97° Horizontal FoV versus the human 210°×150° (See Figure 2.8).

Stimuli. For the categorization task, we asked to distinguish between 15 males and 15 females' bodies expressing neutral, fear and angry expressions with faces blurred extracted from the Bochum Emotional Stimulus Set (BESST; Thoma et al., 2013) developed to measure participants' emotion recognition (Figure 2.9). This stimulus set was synthetically created using the FaceGen 3.5 Modeller and validated in terms of categorization accuracy and the perceived naturalness.

2.3.1.3 Procedure

The procedure largely was similar to the previous experiments. Training took place on Floor 0. Then, participants entered one of the floors for the first time and had to find a neutral object (e.g. a blue box) as quickly and accurately as possible (encoding phase, or T1). They had a maximum of 5 minutes to find it. Once they had found the object, the categorisation task began. Here, participants had to categorise whether the depicted body was 'male' or 'female' by pressing the buttons on their controllers (counterbalanced). The timing of the event in a trial was as follows: a fixation cross for 1000 msec, the target image for 1000 msec, then a mask for 500 msec, and finally a maximum response time of 3000 msec. After completing the categorisation task, participants were returned to the same floor as in the encoding phase. Participants had to find the same object (e.g., box) in the same location again (recall phase, or T2). The entire task was repeated twice, once per emotional condition and in counterbalanced order. Finally, participants completed a series of questionnaires (i.e. demographics and WQ; Claessen & de Rooij, et al., 2016).

Figure 2.8. Examples of male and female expressing fearful, angry, and neutral body expressions extracted from The Bochum Emotional Stimulus Set (BESST; Thoma, Soria Bauser, & Suchan, 2013) are reproduced with permission by the authors.

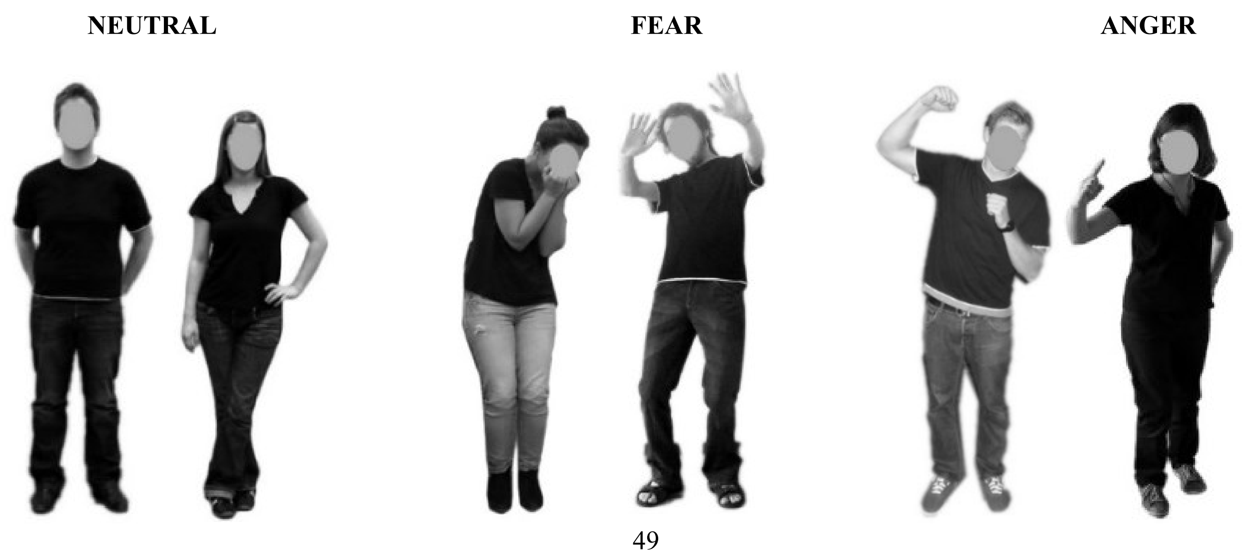


Figure 2.9. Oculus Quest 2 and example of Floor 0 for training in VR.

2.3.1.4 Data Preparation and Statistical Analyses

As in the previous studies, we recorded travel times in milliseconds and the distances travelled from the moment they entered each floor until they reached the target object. For the analyses, we first checked whether our data respected the assumptions of parametric tests. For testing the normality of residuals, we inspected the QQ-plot of the residuals. For the homogeneity of variance, we conducted Leven's tests. For the sphericity assumption, we conducted Mauchly's tests. For both the dependent variables, the assumptions were not respected (see Appendix 4). Therefore, we applied a logarithmic transformation to the two dependent variables to obtain pseudo-normal data. After transformation, the assumptions were not violated anymore. Hence, we proceed with conducting mixed ANOVAs. We reported effect sizes (η^2_p for the F tests) along with the statistical tests. We also made preliminary analyses to test whether the travel time and the distance travelled on each floor was balanced and not dependent on the heterogeneity of the floor maps. A repeated-measures ANOVA comparing the three floors performed on T1 only – when the emotional exposure had not occurred yet – the three maps yielded significant differences in times, $F(2,70) = 4.01$, $p = .002$, $\eta^2_p = .10$, meaning that navigation in the second floor was better than in the other floors (*Floor 1*: $M = 4.49$ sec, $SD = .55$; *Floor 2*: $M = 4.21$ sec, $SD = .47$ *Floor 3*: $M = 4.61$ sec, $SD = .70$) and distances, $F(2,70) = 6.27$, $p = .003$, $\eta^2_p = .15$. (*Floor 1*: $M = 4.92$ um, $SD = .53$; *Floor 2*: $M = 4.52$ um, $SD = .47$; *Floor 3*: $M = 4.77$ um, $SD = .61$). Gender never showed a significant difference neither for times $F(2,35) = 2.89$, $p = .098$, $\eta^2_p = .07$ nor for distances $F(2,70) = .008$, $p = .92$, $\eta^2_p = .00$. The interaction between floors and gender was not significant for travel times $F(2,70) = .51$, $p = .60$, $\eta^2_p = .014$ as well as for distances travelled, $F(2,70) = .13$, $p = .88$, $\eta^2_p = .004$. Thus, there were differences between maps, all participants were faster and travelled shorter distances in Floor 2.

2.3.2 Results

2.3.2.1 Analysis of Travel Times

To determine whether participants' performances were affected by the emotional bodies, we performed a mixed ANOVA 3 (emotional bodies: neutral vs. fear vs. anger) x 2 (gender: female vs. male) x 2 (time: T1 vs. T2) on travel times (means and standard deviations are reported in Table 2.4). The results showed a significant main effect of time, $F(1,35) = 135$, $p < .001$, $\eta^2_p = .79$, participants were faster at T2 rather than T1 showing that they learnt the route and recalled it effectively. The main effect of gender was not significant, $F(1,35) = 1.47$, $p = .23$, $\eta^2_p = .04$, as well as the main effect of bodies, $F(2,70) = .23$, $p = .79$, $\eta^2_p = .007$. Moreover, none of the interactions was significant $F(2,70) < .66$, $p > .76$, $\eta^2_p < .008$. Given the absence of any significant interactions no further analysis were made (Figure 2.10).

Since we found heterogeneities between the maps of the floors, and specifically that floor 2 was explored faster than floors 1 and 3, we run an additional analysis also including a factor accounting for the assignment of the floors to each emotional condition (which varied between participants) which might have influenced the pattern of the results.

We performed an ANOVA 3 (emotional bodies: neutral vs. fear vs. anger) x 2 (gender: female vs. male) x 2 (time: T1 vs. T2) x 3 (floor assignments to each emotion) on travel times. There was still a significant effect of time $F(1,31) = 126$, $p < .001$, $\eta^2_p = .80$. We also found an interaction between emotions and floor, $F(4,62) = 6.27$, $p < .001$, $\eta^2_p = .28$.

Thus, performances of emotional conditions assigned to floor 2 were on average faster than performances not on this floor (*Neutral*: Floor 1: $M = 4.05$, $SD = .36$; Floor 2: $M = 3.67$, $SD = .46$; Floor 3: $M = 4.26$, $SD = .67$; *Fear*: Floor 1: $M = 4.17$, $SD = .45$; Floor 2: $M = 3.67$, $SD = .46$; Floor 3: $M = 4.10$, $SD = .51$; *Anger*: Floor 1: $M = 4.00$, $SD = .52$; Floor 2: $M = 3.80$, $SD = .54$; Floor 3: $M = 4.26$, $SD = .67$). However, there was no interaction between emotions, floors and time, $F(4,62) = .33$, $p = .86$, $\eta^2_p = .02$, meaning that differences between floors did not influence the differences between T1 and T2 due to the emotional conditions. In other words, the lack of difference between emotional conditions when comparing T1 and T2 was not directly influenced by the way participants were assigned to the floors. All other effects were not significant, $F < .86$, $p > .36$, $\eta^2_p < .03$.

2.3.2.2 Analysis of Distance Travelled

To determine whether participants' performances were affected by the emotion manipulations, we performed a mixed ANOVA 3 (emotional bodies: neutral vs. fear vs. anger) x 2 (gender: female vs. male) x 2 (time: T1 vs. T2) on travel times. Means and SD are reported in Table 2.5. The main effect of time was significant, $F(1,35) = 74.1$, $p <.001$, $\eta^2_p = .68$ indicating that the distances travelled were shorter at T2 than T1. The main effects of bodies and gender were not significant, $F(1,35) = .40$, $p = .68.$, $\eta^2_p = .01$, and $F(1,35) = .39$, $p = .54$, $\eta^2_p = .01$, respectively. All the interactions were not significant, $F(2,70) < .85$, $p > .87$, $\eta^2_p < .02$ (Figure 2.11).

As before, we run an additional analysis also including a factor accounting for the assignment of the floor to an emotional condition (which varied between participants) which might have influenced the pattern of the results. Thus, we performed an ANOVA 3 (emotional bodies: neutral vs. fear vs. anger) x 2 (gender: female vs. male) x 2 (time: T1 vs. T2) x 3 (floors assignments to each emotion) on distances travelled. There was still a significant effect of time $F(1,31) = 68.3$, $p < .001$, $\eta^2_p = .68$. We also found an interaction between emotions and floors, $F(4,62) = 12.2$, $p < .001$, $\eta^2_p = .44$, meaning again that performances in each emotional condition was more performant when assigned to the second floor than to the other floors (*Neutral*: Floor 1: $M = 4.67$, $SD = .30$; Floor 2: $M = 4.07$, $SD = .30$; Floor 3: $M = 4.51$, $SD =. 24$; *Fear*: Floor 1: $M = 4.76$, $SD = .39$; Floor 2: $M = 4.19$, $SD = .41$; Floor 3: $M = 4.59$, $SD = .38$; *Anger*: Floor 1: $M = 4.50$, $SD = .38$; Floor 2: $M = 4.14$, $SD = .34$; Floor 3: $M = 4.75$, $SD = .55$). However, there was no interaction between emotions, floors and time, $F(4,62) = .49$, $p = .74$, $\eta^2_p = .03$, again suggesting that the lack of difference between emotional conditions when comparing T1 and T2 was not dependent on the type of floors assigned to each emotional condition. All other effects were not significant, $F < 1.04$, $p > .36$, $\eta^2_p < .03$.

2.3.3 Discussion

We tested the possibility that fearful vs. angry vs. neutral bodies with no visible facial component (i.e. blurred faces) would affect navigation performance, as fearful faces did for men in our previous experiments. In the end, we found that emotional bodies did not differ in their effects on navigation. We only found differences in performance from encoding to recall, suggesting that participants were able to learn and recall a route efficiently. Our gender data were unbalanced and had significant limitations due to the limited observations on which the analyses were performed.

Table 2.4 Means and standard deviations (in parenthesis) of travel time in seconds as a function of gender and emotional conditions with and without the logarithmic transformation.

Times (sec)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	97.9 (56.9)	36.7 (16.9)	61.2 (58.1)	84.5 (43.1)	29.6 (9.44)	54.9 (41.8)
Fear	108 (654.9)	39.1 (29.2)	69.0 (59.1)	88.1 (57.4)	46.0 (35.7)	42.1 (49.9)
Anger	116 (105)	68.2 (118)	47.7 (146)	77.5 (39.1)	38.5 (28.1)	38.9 (42.1)
Times (log)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	4.45 (.51)	3.50 (.48)	0.95 (.57)	4.32 (.52)	3.34 (.34)	.99 (.97)
Fear	4.52 (.58)	3.48 (.56)	1.04 (.65)	4.25 (.73)	3.58 (.73)	0.68 (.79)
Anger	4.50 (.66)	3.69 (.87)	0.81 (.81)	4.22 (.54)	3.47 (.58)	0.74 (.75)

Figure 2.10. Line representing the difference in time travelled in seconds (after the logarithmic transformation) between single encoding (T1) and recalling (T2) sessions (a) and differential score (T1-T) (b) as a function of gender and body emotional conditions. Lower numbers indicate better performances in graph a, and vice versa in graph b. The red line represents male participants, and the blue line represents female participants. Bars represent standard error around the means.

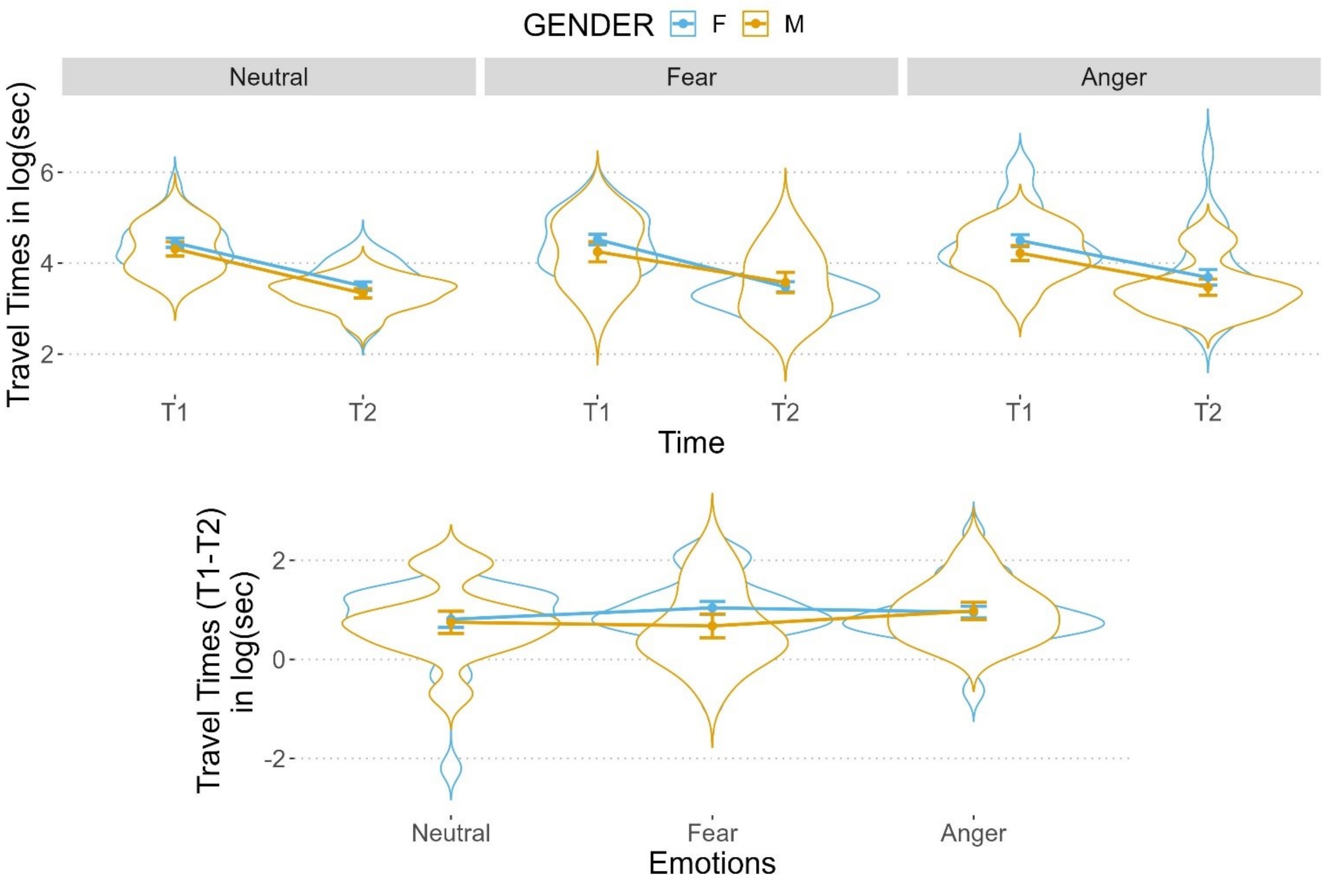
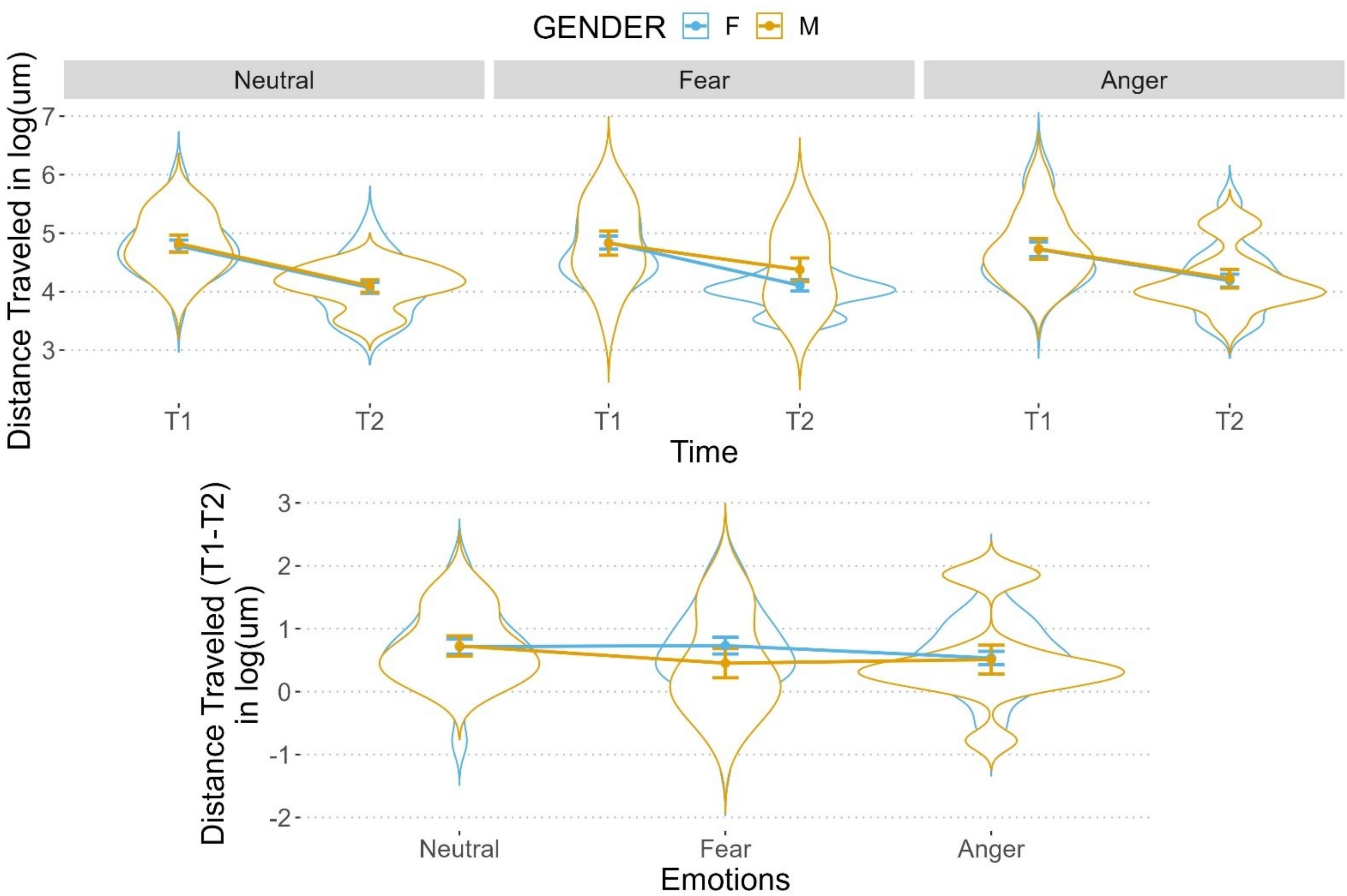


Table 2.5 Means and standard deviations (in parenthesis) of distance travelled in seconds as a function of gender and emotional conditions with and without the logarithmic transformation.

Distance (um)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	137 (81.7)	65.5 (34.1)	71.3 (86.4)	138 (67.6)	63.3 (20.0)	75.1 (66.9)
Fear	148 (87.6)	70.0 (46.7)	78.1 (94.9)	152 (98.4)	97.4 (67.1)	55.0 (92.7)
Anger	141 (114)	78.4 (56.8)	62.9 (97.2)	135 (93.1)	78.6 (49.8)	56.0 (105)
Distance (log)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	4.78 (.52)	4.07 (.48)	.71 (.60)	4.82 (.49)	4.10 (.35)	.73 (.52)
Fear	4.84 (.57)	4.11 (.50)	.73 (.67)	4.83 (.68)	4.38 (.66)	.45 (.77)
Anger	4.72 (.64)	4.19 (.56)	.54 (.54)	4.73 (.58)	4.23 (.52)	.51 (.76)

Figure 2.11. Line representing the difference in distance travelled in um, Unity measure (after the logarithmic transformation) between single encoding (T1) and recalling (T2) sessions (a) and differential score (T1-T) (b) as a function of gender and body emotional conditions. Lower numbers indicate better performances in graph a, and vice versa in graph b. The red line represents male participants, and the blue line represents female participants. Bars represent standard error around the means.



2.4 EXPERIMENT 3: Effect of Negative Emotional Contexts on Wayfinding in VR

The first two experiments showed that faces and bodies influenced navigation differently. These are social stimuli, i.e. they convey emotional states expressed by an actor. We do not know whether the effect found for fearful faces (but not for bodies) is specific to the social nature of the stimulus used for our manipulation. It was, therefore, useful to test the effect that a (threatening) non-social stimulus might have on people's navigation. This would test with greater precision the specificity of the influence of faces on navigation. Indeed, so far, we had evidence that the threat induced by a contextual scenario, like faces, can influence wayfinding performance. Another alternative would reject this idea, suggesting that the social value of an emotional face is not comparable to that of an emotional but non-social context.

In the present experiment, we asked participants to navigate the same virtual environment as in the previous experiments. Crucially, participants were exposed to two emotional conditions in between: one consisting of a series of threatening contextual images and the other consisting of reassuring contextual images. To increase the magnitude of the potential effect of negative contexts, which may be less salient and less powerful than emotional faces, we decided to compare threatening (i.e., negative) and reassuring (i.e., positive) contexts (rather than neutral contexts). In this way, we could also test the potential effect of positive stimuli on navigation, which has not been considered in previous studies. If it was true that emotional contexts can influence wayfinding, then we might expect an effect consistent with our previous experiment, with males exposed to negative emotional stimuli decreasing their performance more than females, which might be consistent with some literature on the influence of emotional landmarks (e.g., Litvak, 2012; Nori et al., 2023; Piccardi et al., 2020). Differently, if emotional contexts per se are not sufficient to elicit such differences, we should not find any difference between the two emotional conditions.

2.4.1 Method

We employed a 2 (time: time 1 vs. time 2) x 2 (emotional context: threatening vs. reassuring) x 2 (gender: male vs. female) mixed design. We measured travel times and distance travelled as dependent variables. Participants were exposed to the two emotional conditions in random sequence; thus, the emotional conditions and times in VR (T1 vs. T2) were within-subject factors and gender was the only between-subjects factor.

2.4.1.1 Participants

Due to the differences in the design and the fundamental differences in materials employed, it was not possible to use Experiment 1's effect sizes to calculate a suggested sample size. We collected data from participants for 10 months in UK and we decided to reach at least the same sample size of Experiment 1. Eventually, we collected a sample of 50 university students (25 males, M_{age} = 24.4, SD_{age} = 5.58; 25 females, M_{age}= 22.1, SD_{age} = 4.18). According to a sensitivity power analysis, we could observe a minimum effect size of f = .41 (η^2_p = .14) with power = .80 at alpha = .05. We applied the same inclusion and exclusion criteria of the previous experiments.

The study was approved by the ethics committee of the University of Surrey (FEO_FHMS 21-22 023 EGA). Participants received written informed consent and were treated in accordance with the Declaration of Helsinki. Participants were paid in exchange for their participation with £7 Amazon Vouchers.

2.4.1.2 Materials

Apparatus. We used the same virtual environments of Experiments 1-2. This time we employed the Oculus Rift Touch line of virtual headsets that have a 1080 x 1200 LCD 80 Hz and a field of view of 87°×88° versus the human 210°×150°.

Scenes. 160 freely available pictures of contexts were collected online through websites. They depicted a wide range of reassuring or threatening environments with both natural and city scenarios; we decided to balance these latter types of scenarios as they might lead to different types of emotional reactions (Kaplan, 1995) and because the categorization task was based on this distinction. They did not include any human component or disturbing images.

Thirty-eight participants were asked how much each of the 160 images was threatening or reassuring on a scale from 1 (threatening) to 7 (reassuring). We selected 60 images (See Figure 2.12), 30 threatening and 30 reassuring contexts (15 cities and 15 nature landscapes in each category; threatening city: M = 2.14, SD =.58; threatening nature: M = 2.12, SD = .78; reassuring city: M = 5.70, SD = .69; reassuring nature: M =5.78, SD =.70. The difference between reassuring cities (M = 5.76, SD = .69) and reassuring natures (M = 5.78, SD = .70) in perceived threat was not significant $t(37)$ = -.28, p = .77, as well as the difference between threatening cities (M = 2.15 , SD = .58) and threatening natures (M = 2.12 , SD = .75), $t(37)$ = -.31, p = .75. Furthermore, we measured how people felt about the scenarios (1 = negatively, 7 = positively). The difference between reassuring cities (M = 5.56, SD = .72) and reassuring natures (M = 5.85, SD = .71) was significant, with nature scenes being slightly more positive, $t(37)$ = -2.21, p = .0.03; while the difference between threatening cities (M = 2.08 , SD = .75) and threatening natures (M = 2.14 , SD = .83) was not significant $t(37)$ = -.74, p = .46. In terms of perceived lightness of the pictures (1 = low, 7 = high), the difference between reassuring cities and reassuring natures was significant, $t(36)$ = -4.58, p <.0.01; with nature scenes (M = 5.83 , SD = .67) being perceived as more lighted than city scenes (M = 5.49, SD = .78); while the difference between threatening cities (M = 2.07, SD = .47) and threatening natures (M = 2.11, SD = .55) was not significant, $t(36)$ = -.56, p = .58.

Figure 2.12 Two examples of images selected for the Second Experiment.

2.4.1.3 Procedure

The procedure was similar as that of the previous experiments, but with different headset (see Figure 2.13) and different design. Training took place on Floor 0. Then, participants entered one of the floors for the first time and had to find a neutral object (e.g. a blue box) as quickly and accurately as possible (encoding phase, or T1). They had a maximum of 5 minutes to find it. Once they had found the object, the categorisation task began. Here, participants had to categorise whether the depicted context was 'nature' or 'city' by pressing the buttons on their controllers (counterbalanced). The timing of the task was as follows: a fixation cross was displayed for 1000 msec, the target image for 1000 msec, then a mask for 500 msec; at the end they had a maximum response time of 3000 msec. At the end of the categorisation task, participants were returned to the same floor as in the encoding phase. Participants had to find the same object (e.g., box) in the same location again (recall phase or T2). The entire task was repeated twice, once per emotional condition and in counterbalanced order. Finally, participants completed a series of questionnaires, were debriefed, and paid.

Figure 2.13. Oculus Rift Touch**.**

2.4.14 Data Preparation and Statistical Analyses

As in the previous studies, we recorded travel times in milliseconds and the distances travelled from the moment participants entered each floor until they reached the target object. For the analyses, we first checked whether our data respected the assumptions of parametric tests. For testing the normality of residuals, we inspected the QQ-plot of the residuals. For the homogeneity of variance, we conducted Leven's tests. For the sphericity assumption, we conducted Mauchly's tests. For both the dependent variables, the assumptions were not respected (see Appendix 5). Therefore, we applied a logarithmic transformation to the two dependent variables to obtain pseudo-normal data. The transformation shifted and centralized the extremities, reducing the impact of extreme observations. After transformation, the assumptions were not violated anymore.

Hence, we proceeded with conducting mixed ANOVAs. We reported effect sizes (η^2_p for the F tests) along with the statistical tests. We also made preliminary analyses to test whether the travel time and the distance travelled on each floor was balanced and not dependent on the heterogeneity of the floor maps. A repeated-measures ANOVA comparing the three floors performed on T1 only – when the emotional exposure had not yet been occurred – the three maps yielded no differences in times, $F(2,96) = .16$, $p = .68$, $\eta^2_p = .003$ (*Floor 1*: $M = 4.43$ sec, $SD = .43$; *Floor 3*: $M = 4.46$ sec, $SD = .46$) and distances, $F(2,96) = 4.07$, $p = .05$, $\eta^2_p = .07$. (*Floor 1*: $M = 4.87$ um, $SD = .40$; *Floor 3*: $M = 4.73$ um, $SD = .45$). Thus, participants were not biased by maps' heterogeneity.

2.4.2 Results

2.4.2.1 Analysis of Travel Times

To determine whether participants' performances were affected by the emotional scenarios, we performed a mixed ANOVA 2 (scene: reassuring vs. threatening) x 2 (gender: female vs. male) x 2 (time: T1 vs. T2) on travel times. Means and standard deviations are reported in Table 2.6. The results showed a significant main effect of time, $F(1,48) = 139$, $p < .001$, $\eta^2_p = .74$, participants were faster at T2 rather than T1 showing that they learnt the route and recalled it effectively, and a significant main effect of gender was also found, $F(1,48) = 30.43$, $p < .001$, $\eta^2_p = .38$, with males on average being faster than females in reaching the object. The main effect of scenes was not significant, $F(2,96) = .06$, $p = .80$, $\eta^2_p = .001$. Moreover, none of the interactions was significant $F(2,96) < 1.39$, $p > .24$, $\eta^2_p < .001$ (Figure 2.14). Given the absence of any significant interactions no further analyses were made.

2.4.2.2 Analysis of Distance Travelled

To determine whether participants' performances were affected by the emotion manipulations, we performed a mixed ANOVA 2 (scene: reassuring vs. threatening) x 2 (gender: female vs. male) x 2 (time: T1 vs. T2) on travel times. Means and standard deviations are reported in Table 2.7. The main effect of time was significant, $F(1,48) = 76.5$, $p < .001$, $\eta^2_p = .61$ indicating that the distances travelled were inferior at T2 than T1. The main effects of gender and scenes were not significant, ($F(1,48) = 3.07$ $p = .08$, $\eta^2_p = .06$; $F(1,48) = .51$, $p = .48$, $\eta^2_p = .01$, respectively). All the interactions were not significant, $F(2,96) < 2.71$, $p > .10$, $\eta^2_p < .05$ (Figure 2.15).

2.4.3 Discussion

We evaluated the possibility that threatening contexts (vs. reassuring contexts) influenced wayfinding performances as fearful faces did in our previous experiments. Our experiment does not suggest that this is the case, as emotional contexts did not differ in their effect. We found only differences in terms of performance from encoding to recalling, showing that participants were able to improve their performances after the first navigation, and differences in gender, with travel times faster for males than females (but not distance travelled).

Table 2.6. Means and standard deviations (in parenthesis) of travel time in seconds as a function of gender and emotional conditions with and without the logarithmic transformation.

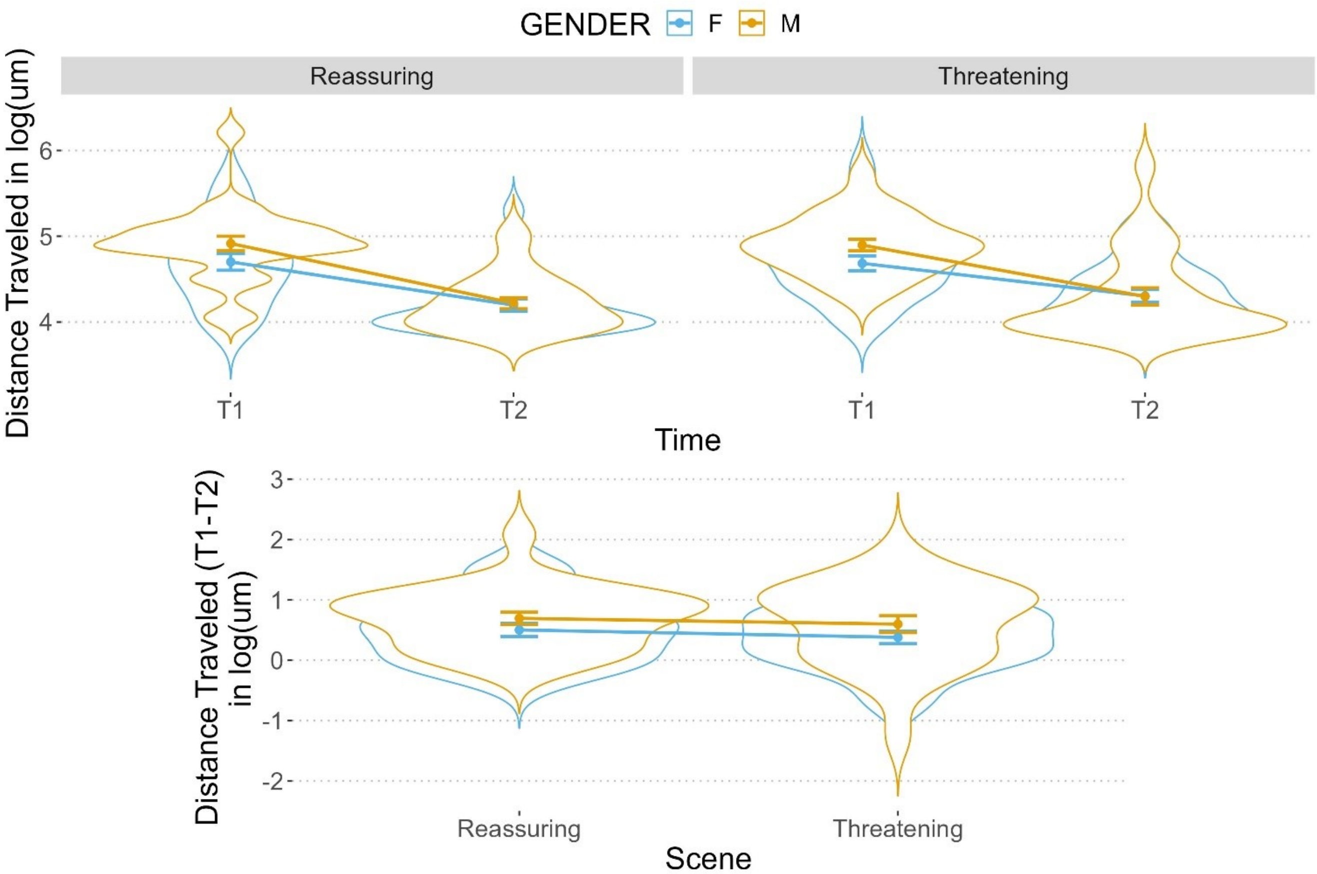
Times (sec)	*Females*			*Males*		
Scenes	T1	T2	T1-T2	T1	T2	T1-T2
Reassuring	121 (57)	59.5 (35.9)	61.9 (66.1)	79 (44)	30.8 (14.1)	48.9 (44.5)
Threatening	104 (44.4)	59.3 (31.5)	44.7 (47.7)	74 (30.7)	38.3 (29.5)	35.7 (48.6)
Times (log)	*Females*			*Males*		
Scenes	T1	T2	T1-T2	T1	T2	T1-T2
Reassuring	4.71 (.42)	3.92 (.58)	0.7 (.63)	4.28 (.43)	3.25 (.52)	0.9 (.55)
Threatening	4.56 (.42)	3.95 (.39)	0.6 (.50)	4.23 (.37)	3.47 (.55)	0.7 (.77)

Figure 2.14. Line representing the difference in distance travelled in seconds (after the logarithmic transformation) between single encoding (T1) and recalling (T2) sessions (a) and differential score (T1-T) (b) as a function of gender and emotional conditions. Lower numbers indicate better performances in graph a, and vice versa in graph b. The blue line represents female participants, and the red represents male participants. Bars represent standard error around the means. Refer to Table 2.6 for non-transformed data.

Table 2.7 Means and standard deviations (in parenthesis) of distance travelled in seconds as a function of gender and emotional conditions with and without the logarithmic transformation.

Distance (um)	*Females*			*Males*		
Scenes	T1	T2	T1-T2	T1	T2	T1-T2
Reassuring	123 (63.6)	71.8 (34.1)	52.1 (70.4)	150 (81.9)	71.9 (27.9)	78 (85.9)
Threatening	119 (64.3)	79.4 (33.8)	40.1 (70.4)	132 (52.2)	61.7 (63.2)	56 (93.1)
Distance (log)	*Females*			*Males*		
Scenes	T1	T2	T1-T2	T1	T2	T1-T2
Reassuring	4.70 (.48)	4.20 (.34)	0.5 (.54)	4.92 (.42)	4.22 (.32)	0.69 (.51)
Threatening	4.68 (.43)	4.30 (.37)	0.38 (.52)	4.90 (.39)	4.30 (.50)	0.59 (.69)

Figure 2.15 Line representing the difference in distance travelled in seconds (after the logarithmic transformation) between single encoding (T1) and recalling (T2) sessions (a) and differential score (T1-T) (b) as a function of gender and emotional conditions. Lower numbers indicate better performances in graph a, and vice versa in graph b. The red line represents female participants, and the blue represents male participants. Bars represent standard error around the means. Refer to Table 2.7 for non-transformed data.



2.5 GENERAL DISCUSSION

Although emotions significantly influence human behavioural processes, the potential influence of emotional processing on spatial navigation has been largely overlooked. Therefore, in the present study, we investigated how exposure to emotional stimuli affects wayfinding behaviour. In our study, participants navigated twice in three virtual reality environments (different floors of an office building). Each condition consisted of an initial encoding phase (i.e., autonomously learning a path to a target object) and a subsequent recalling phase (i.e., finding the same object at the same location in the previously explored environment). Emotional stimuli were presented between the two phases. In Experiment 1, three emotional facial expressions (anger, fear, neutral) were presented for an unrelated task (i.e., gender categorisation) and in counterbalanced order. In Experiment 2, the same emotional bodily expressions were shown, always in counterbalanced order. In Experiment 3, we showed threatening or reassuring contextual scenes. We measured travel times and distances travelled in the two phases as proxies for wayfinding performance.

In all experiments, participants were faster and travelled shorter distances in the retrieval phase than in the encoding phase, in line with our hypothesis. In addition, males were on average faster and travelled shorter distances than females, which may be consistent with their greater wayfinding abilities (Coluccia & Louse, 2004). However, the hypothesised effect of negative emotions on participants' navigation performance was only observed in Experiment 1 and was better explained by a higher-order interaction with gender. Indeed, fearful faces only disrupted male's navigation, while this was not the case for females, who were unaffected. Angry and neutral faces had no effect on participants' performance. We observed also that fearful and angry faces differed in their effect on the performance of males (but not females). Such differences were not extended to bodies or emotional scenes. A possible explanation for the effect of fearful faces on navigation performance is possibly related to evolutionarily based behavioural responses elicited by such emotions (e.g., approach/avoidance, fight/flight; Adams et al., 2006; Kreibig et al., 2007; Stins et al., 2011). To promote survival, humans may be evolutionarily predisposed to prioritise the processing of threatening stimuli (Öhman et al., 2001; Rotteveel et al., 2001). In the broader context of navigation, the perception of emotional faces may be relevant for survival because they can be processed as social information about the environment (Elfenbein, 2014; Hareli & Parkinson, 2008).

Within this interpretive framework, participants exposed to other people expressing fear may have prioritised the detection of an unidentified threat in the surrounding context, either a person or an object (e.g., fire in the office). Even after the faces were no longer visible, the lingering sense of threat may have continued to affect their ability to navigate the environment. In contrast, anger often represents a threat that is more immediate and directed at the observer in the present context. Indeed, angry faces may have been interpreted as indicating interpersonal threats (i.e., aggressive intentions), and once the faces disappeared, the perceived threat vanished and did not affect subsequent navigation. This distinction suggests that the nature of the threat, whether directed at the observer or emanating from an unknown source, may play a crucial role in shaping an individual's navigational responses. Future studies can address whether our speculations might justify our findings.

We could also speculate that negative emotion processing may have affected spatial navigation (in males), as working memory (WM), and specifically visuospatial working memory (VSWM), contributes to both facial emotion processing and spatial navigation (Dehn, 2011; Baddeley et al., 2012; Dickerson & Atri, 2014; Brown & Chrastil, 2019).

The VSWM is responsible for processing and maintaining visuospatial information and plays an important role in spatial navigation tasks involving the identification of objects and their respective spatial locations (Garden, 2002; Coluccia & Louse, 2007; Nori et al., 2009). Furthermore, the processing of negative emotions also requires significant VSWM resources (Tyng et al., 2017). In particular, fearful expressions have been associated with a detrimental effect on VSWM performance (see also Lindström & Bohlin, 2012; Berggren et al., 2017; Shields et al., 2017; Curby et al., 2019). Experiencing negative emotions can inhibit the retention phase of VSWM, affecting the consolidation and retrieval of spatial information (Shackman et al., 2006; Moran, 2016). For these reasons, it would be plausible to expect that processing negative facial expressions would disrupt wayfinding by diverting people's limited VSWM resources.

Furthermore, although females usually underperform in the wayfinding task (Coluccia & Louse, 2004), they might excel in emotion processing (Olderbak et al., 2019). Such superior ability in processing facial emotions might have helped them to control the influence of fear on their wayfinding abilities. As illustrated above, females tend to use a greater variety of emotion regulation strategies than males (Goubet & Chrysikou, 2019). In contrast, males experienced a significant decline in performance following exposure to fearful faces. In a similar vein, the decrease in performance could be due to the higher cognitive load on VSWM that fear processing imposed on males, whereas females found it less demanding and managed the demand better. Future studies should examine gender differences in VSWM performance in emotional face tasks to address this open question.

Moreover, we did not find an effect due to emotional scenes (Experiment 3). We could interpret this result as being due to the different nature of such emotional stimuli, i.e. their non-social nature compared to faces. Thus, social stimuli might be a stronger driver of human behaviour than non-social stimuli, especially for navigation (Dalton et al., 2019). However, we also used emotional bodies (Experiment 2), which are stimuli with high social relevance compared to scenes (de Gelder et al., 2015). Thus, we expected to extend our initial findings with faces to bodies. Unexpectedly, we did not find the same effects. Instead, emotional bodies were not effective. One possible explanation is that emotions perceived from faces in the context of navigation activate stronger behavioural responses than other types of stimuli that ultimately influence wayfinding (e.g., Öhman et al., 2001). Thus, in our experiments, we may have observed a face-specific effect that is difficult to generalise to other types of stimuli.

Furthermore, another factor that may have contributed to the lack of extension of the result of Experiment 1 in our follow-up experiments is that we exposed participants to emotional stimuli without asking them to actively evaluate the emotional content. This experimental design was chosen to investigate the influence of emotions on navigation when the experimenters do not ask individuals to engage in emotional processing, similar to scenarios where people walk through public spaces and encounter emotional stimuli without necessarily being forced to pay attention. Although individuals may not engage in explicit interpretation of these stimuli, we hypothesised that emotions could still influence the subsequent task through repeated exposure (during the categorisation task). It may be that this approach is appropriate for inducing an effect with face stimuli, but not with other stimuli. Interestingly, the approach we chose may appear to be at odds with the theoretical framework of appraisal theory (Moors & Fischer, 2019), which posits that emotional stimuli primarily influence human behaviour when they are task-relevant, rather than when they are task-irrelevant.

A comparison of task relevance was beyond the scope of the present research; indeed, we did not include a task-relevant condition. However, it may be that the effects of bodies and scenes increase when participants engage in a task-relevant version of the current paradigm, i.e. a task in which they are explicitly instructed to address the emotional nature of the stimuli. Previous studies of performance-based measures did not find effects when emotional (and threatening) stimuli were task-irrelevant (e.g., Mancini et al., 2020, 2022; Mirabella, 2018; Mirabella et al. 2023), but there were notable differences between our experimental approach and that of these studies. Future research should assess the limits of emotion appraisal theory also for navigation behaviours, to test whether task relevance (vs. irrelevance) can increase the likelihood of observing similar effects with different types of emotional stimuli other than faces.

Finally, we also acknowledge that our sample sizes were small (especially in Experiment 2, which also suffered from an unbalanced gender distribution) and allowed only limited inference: future research should increase them in order to test the results of our first investigation with additional power. Furthermore, we did not consider the effects of positive facial and bodily emotions in our research. Positive emotions convey different information and effects than negative ones, including stress reduction and recovery effects (Fredrickson, 2005). Although we did not find a difference between threatening and reassuring scenes, it is possible that positive faces or bodies may still have an effect.

Concluding, our results suggest that negative emotions can indeed influence spatial navigation. Fearful facial expressions impacted the wayfinding performance of males more significantly than both angry and neutral expressions, without a comparable effect on females. This gender-based distinction highlights the intricate interplay among emotion processing and navigational performances which might be due to several reasons.

Overall, Chapter 2 provides initial and fundamental evidence of the role of emotions, and specifically facial emotions, in influencing navigation, finding emotion-specific and gender specific effects. This adds evidence to the first three open issues but leaves open *what* specific navigation sub-components can be influenced. The next chapter will provide an answer to this question.

CHAPTER 3:

THE EFFECT OF EMOTIONAL FACIAL EXPRESSIONS ON SPATIAL NAVIGATION DOMAINS

CHAPTER 3: THE EFFECT OF EMOTIONAL FACES ON NAVIGATION DOMAINS

3.1 Introduction

While navigating, individuals may come across others experiencing various others' emotional states, such as anger or fear. Surprisingly, there is limited understanding of how processing these emotions affects a person's navigation abilities and their subcomponents (i.e., landmark, location, path). Little is known about the impact of emotional faces on navigational domains outcomes. In this chapter, we investigate the consequences of exposure to other people's emotional faces when performing spatial navigation tasks. Specifically, we will measure whether and how facial emotion processing influence spatial navigation domains: landmark, location, and path.

3.1.1 Spatial Navigation Domains

As previously said, spatial navigation is a complex and multifaceted process that has been extensively studied by researchers who have adopted many perspectives and measures over the years. Historically, research on wayfinding behaviour and spatial cognition has distinguished among different strategies used for reaching a destination (Burgess, 2006; Klatzky, 1998). These are egocentric and allocentric processes, landmark representation, route and survey knowledge, which are assumed to be ordered from the simplest to the most complex strategy for navigation (Claessen & van der Ham, 2014; Siegel & White, 1975; Wolbers & Büchel, 2005; Wolbers et al., 2004). Van der Ham and colleagues (2020) noted that these perspectives have been rarely addressed altogether. Indeed, they summarised them and provided a framework to guide future research. Their classification of theory-based domains includes the landmark, location, and path domains.

The *landmark domain involves* the identification of unique features or objects in the environment that act as reference points and help individuals make decisions about direction and location (Bécu et al., 2023). This domain answers the 'what' question. Recognition of previously encountered landmarks can test this ability (Janzen, 2008). The acquisition and updating of landmarks is fundamental for maintaining orientation while moving (Fernandez et al., 2019). Landmark-based updating involves the recognition of specific features or locations in the environment, drawing on either internal or external memory. Landmark-based updating minimises the errors of dead reckoning updating, also known as path integration, which monitors components related to locomotion such as speed, acceleration, and travel time. This process continuously updates one's position and orientation based on self-motion cues, helping to maintain a sense of place in unfamiliar environments. However, it has limitations. It only provides information about the location of a new point in relation to a previously visited point. Landmark-based processes help to correct such errors. The acquisition of cognitive maps is a gradual construction and involves knowledge integrated from different sources, and memory for landmarks is fundamental (Keil et al., 2021).

The *location domain* includes places that can be visited or imagined, and the routes that connect them. These routes are the most direct way to get from one place to another and are often used to navigate between landmarks. It is, therefore, concerned with the question of *'where'*. Traditionally, two different 'frames' for spatial representation have been recognised: the egocentric frame, which contains information about the individual's location in the environment, and the allocentric frame, which contains spatial cues about the relative positions of objects (Tolman, 1948). The egocentric frame gives rise to body-centred representations that are crucial for visuomotor control (Milner & Goodale, 2008). In contrast, the allocentric frame, which is thought to develop later in life, relies on world-based coordinates and describes locations in terms of object-to-object relationships (Bremner & Bryant, 1977; Burgess et al., 2004; Siegel & White, 1975). Recent cognitive models increasingly focus on understanding the interplay between egocentric and allocentric frames and how they collectively contribute to efficient spatial skills (Avraamides & Kelly, 2008). Navigation skills require the flexible use and combination of both egocentric and allocentric strategies, as individuals may show variability in their preference for either strategy (Marchette et al., 2011).

The *path domain* is the most complex aspect as it answers the question 'how to get there'. It involves the spatial relationships of a landmark and how its location relates to other elements in the environment. Path route knowledge involves remembering a particular route to reach a location, based on the spatial context of landmarks and their relationships to our position. Path survey knowledge, on the other hand, allows for a representation of the spatial configuration from a bird's eye view, forming cognitive maps of the environment (Lynch, 1960; Rand, 1969; Siegel & White, 1975). This information can be represented either imaginatively or propositionally, such as in numerically specified distances (Thorndyke & Hayes-Roth, 1982; Montello, 1998).

A critical feature of navigation is gender differences (Fischer, Kret, & Broekens, 2018; Olderbak et al., 2019; Munion et al., 2019). In general, males are thought to outperform females in spatial navigation and memory tasks, a difference that may be due to several interacting biological, cultural, and social factors (Coluccia & Louse, 2004; Clint et al., 2012; van der Ham et al., 2021). However, there are additional specific differences in domains that may be related to different strategies or skills used for navigation tasks. For example, females may use landmark-based navigation more often and thus excel at such tasks, whereas males may prefer Euclidean or directional cues and, thus, excel at location tasks and survey path knowledge (Astur et al., 2006; Barkley & Gabriel, 2007; Levy, Astur, & Frick, 2005, O'Laughlin & Brubaker, 1998; Saucier et al., 2002). However, van der Ham at al. (2020) conducted a large-scale representative study on an adult sample of varying ages and found only a small male advantage in path route knowledge and even smaller in landmark and location allocentric strategies. Thus, new research seems necessary to address gender differences in the three domains. Spatial navigation does not often take place in neutral and impersonal environments. When walking through the streets of a city or entering an unfamiliar building, different types of information extracted from the environment influence navigational performance (e.g., traffic signs, flashing lights, barking dogs), potentially enhancing or constraining goal attainment (Poucet & Save, 2017). Evidence suggests that we are selective, flexible, and adaptive to this large number of stimuli: when we have to remember a route to a destination, we are likely to filter out irrelevant information and stick to the plan. However, some stimuli can overcome such a filter and drastically influence the outcome of navigation (i.e., emotional faces) (Ekstrom & Isham, 2017; Dalton et al., 2019).

3.1.2 The influence of emotion processing on spatial navigation

The face is a communication tool that provides valuable information about others, particularly their emotional states (Ekman, 1978). Emotion processing enables individuals to recognise emotional expressions and extract relevant social information from faces. Faces convey positive and affiliative as well as negative and arousing affect (Marsh et al., 2005). As part of everyday social life, people recognise faces in the environment and identify their emotional expressions and the spatial location in which they were seen with precision and speed (White & Burton, 2022).

As we move about, we often look at another person's facial expressions to understand whether our own behaviour is appropriate to the situation around us. In fact, people convey considerable information relevant to the management of social situations (Langfeld, 1918). Emotions are ubiquitous cues that can influence many human cognitive functions (Schupp et al., 2003; Pourtois et al., 2004; Bisby & Burgess, 2014). Indeed, emotional facial stimuli, especially negative ones, can interfere with the processing of other stimuli in the same environment and capture more attentional resources due to their higher adaptive salience (Vuilleumier et al., 2001; Vaish et al., 2008). Research has consistently shown that emotional faces are identified with greater accuracy and speed than other changing objects in the environment (Jenkins et al., 2005; Reinders et al., 2005). Two facial emotions in particular may be relevant for navigation: fear and anger. Faces that convey fear communicate vulnerability or submission to others and signal a need for protection or help. Consequently, fear elicits empathetic, caring, or supportive responses from others (Ishikawa et al., 2021; Phelps, Ling & Carrasco, 2006). In terms of its impact on cognition, fear tends to impair performance in visuospatial working memory – which is essential for navigational performance – by reducing the capacity to encode and consolidate visuospatial information (Curby et al., 2019, Kensinger & Corkin, 2003; but see also Sessa et al., 2011; Stout et al., 2013). In addition, fearful stimuli tend to capture attention and interfere with the allocation of attentional resources to other tasks (Vuilleumier, 2005).

In contrast, anger prepares individuals for confrontational and intrapersonal behaviours by mobilising energy to approach and overcome obstacles or threats. Experiencing anger can increase approach tendencies and motivate individuals to assert their position or challenge others, whereas perceiving anger in others can lead to aversive and avoidant behaviours (Seidel, 2010). In contrast to fear, anger may not have the same impairing effect on visuospatial working memory, nor does it capture attention to the same extent as fear (Simione et al., 2014; Vuilleumier, 2005). Furthermore, anger may potentially facilitate spatial memory by activating the prefrontal cortex, which is also involved in cognitive control (Churchwell et al., 2010; Santesso et al., 2008). Although we do not specifically investigate the effect of fearful or angry faces on such cognitive functions, memory and attention are the basis for engaging in spatial cognition and navigation tasks. Thus, it is likely that if fear and anger processing can alter performance on basic cognitive tasks, it may also affect spatial navigation tasks.

Most of the research on the interplay between emotion and navigation has explored the role of emotional (non-social) landmarks. For example, a study by Ruotolo et al. (2018) found that people who watched someone else walk a route with positive landmarks were more accurate in locating the landmarks along the route and tracing the route. In another study, Palmiero and Piccardi (2017) found that both positive and negative emotional landmarks equally enhanced path learning compared to neutral emotional landmarks. Furthermore, positive emotional landmarks improved the reproduction of the path on the map compared to negative and neutral emotional landmarks. But there are some exceptions. For example, our own research presented in the previous chapter 2 showed that exposure to fearful faces, but not angry faces, can influence wayfinding performance in a realistic virtual reality environment. Importantly, we found evidence of this effect only for male participants, but not for female participants. Indeed, there are significant gender differences in the perception of emotions in navigation. On the one hand, studies have found that females may be better at recognising emotions from facial expressions (Hoffman et al., 2010; Kret & De Gelder, 2012; Montagne et al., 2005; cf. Fischer, Kret, & Broekens, 2018), on the other hand males show greater behavioural responses to threatening cues, such as fearful or angry faces, than females (Han, 2008; Kret & De Gelder, 2012).

3.2 EXPERIMENT 4: The Effect of Negative Emotional Expressions on Navigational Domains

The purpose of this experiment was to understand how negative facial emotions might affect domains of spatial navigation. Although the research presented in the previous chapters made a step forward in discovering the interplay between emotions and navigation by using a virtual reality environment, it measured secondary outcomes of navigation (i.e., travel time and distance travelled) and was not suitable for measuring in depth the influence of emotion processing on navigation domains. Therefore, this experiment was aimed at filling such a gap and extend our previous findings.

We showed participants a recording of an avatar (in first-person perspective) travelling a route in a realistic, small-scale virtual environment (i.e., an office floor). Participants were asked to pay attention to the route, observe the objects, and try to imagine the map layout of the place. They then performed a gender categorisation task in which they were shown 90 faces expressing one of three emotional expressions (i.e. neutral vs. fear vs. anger) and had to indicate their gender. This task was designed to influence participants by exposing them to multiple emotional faces, and we assumed that people would process emotional expressions even when not asked to do so (see previous chapter).

We then measured the influence of emotion processing on navigation domain abilities through six independent tasks inspired by previous research and tapping the three domains presented above (e.g., van der Ham et al., 2020; Wiener et al., 2012). Specifically, we developed measures that were close to the conceptual definitions of the domains in which, according to the literature reviewed, gender differences are more likely to occur. Thus, we aimed to create six tasks to measure Task 1) landmark recognition: without contextual cues around the object; Task 2) location-egocentric: landmark identification with contextual cues around the object; Task 3) path-route: route ordering; Task 4) path-route: directional pointing; Task 5) path-survey: map recognition; Task 6) location-allocentric: landmark positioning on a 2D map.

Based on previous research using a wide range of tests of spatial navigation and cognition, and consistent with our previous findings (Chapter 2), we expected a male advantage to be likely found in spatial tasks (Coluccia & Louse, 2004), but that females may be better at landmark-based tasks (Sandstrom et al., 1998). Furthermore, recent findings on more than 10,000 participants and using measures similar to the present research reported a small male advantage for landmark and path route location domains, path-allocentric reference was marginal (van der Ham et al., 2020). We therefore expected to find a potential male advantage in tasks related to path route knowledge (Hp1) and investigated what happens in the other domains. Based on our previous findings and the evidence reviewed so far, we hypothesised an effect of exposure to fearful faces that might be detrimental for such tasks (Hp2), although it was not possible to predict which measure would be more affected by fear (vs. anger vs. neutral). In addition, we know from our previous findings, albeit with a behavioural measure of wayfinding, that males may be more negatively affected by fearful (vs. angry vs. neutral) faces than females. Thus, we hypothesised that a similar pattern might be replicated in these tasks, which involve domains essential for wayfinding (van de Ham et al., 2020). Thus, fearful facial processing might disrupt more the performance of males than females (Hp3).

3.2.1 Method

We employed a 3 (emotion: neutral vs. fearful vs anger) x 2 (gender: female vs. male) between subject's design, with each task as dependent variable. The dependent variables (i.e., six tasks performance) were coded as binomial outcomes, with 0 as incorrect and 1 as correct response.

3.2.1.1 Participants

We could not establish the size of the effect due to the novelty of the design. We aimed at finding the smallest effect size of interest of OR = 1.68 in a binomial logistic regression, which configures as a small effect to Chen et al. (2010), with power = .80 at alpha = .05 (G*power). The analysis returned a sample of 481 participants. Eventually, we collected 485 participants on Prolific Academic running the study online. Three participants were excluded as they did not report their gender. The final sample consisted of 482 participants (239 males, M_{age} = 21.9, SD_{age} = 10.1; 243 females, M_{age} = 21.7, SD_{age} = 11.9). About eighty participants were assigned to each condition (Males: *Neutral* N = 77, *Fear* N = 81, *Anger* N = 81; Females: *Neutral* N = 84, *Fear* N = 80, *Anger* N = 79). We recruited participants through the Prolific Academic platform and compensated them with £9.00 per hour (£3 for 20 minutes of the experiment), which aligns with the recommended compensation amount. To address potential limitations associated with online studies, we implemented several precautions by adhering to exclusion criteria, including neurological conditions, mild cognitive impairment or dementia, colour blindness, and autism spectrum disorder. To mitigate bias stemming from a single population during data collection (e.g., young students at a university in a large city), we aimed to recruit participants worldwide. The selection was limited to English speakers aged 18 to 60 to avoid discrepancies in results due to natural declines in navigational functionality with aging (Cognè et al., 2017).

The research protocol received approval from the local university ethics committee of the University of Surrey (FEO_FHMS 21-22 023 EGA) and participants were treated in accordance with the principles outlined in the Declaration of Helsinki. Participants were required to review and sign the informed consent before joining.

3.2.1.2 Materials

The experiment was programmed by means of Qualtrics and access was restricted to participants with a computer device. It lasted 20 minutes in total and consisted of a short video recording of a person navigating an environment, a gender categorisation task, six navigation tasks and additional measures (i.e., demographics, WQ; Claessen & de Rooij, et al., 2016).

Navigation video recording. We recorded a video of the virtual 'office building' created for our previous studies and presented a short two-minute film to participants (see Figure 3.1). Once started, participants could not stop the program. The virtual environment, developed using the cross-platform game engine Unity, realistically simulated a standard office floor. The recording focused on a single floor. The video showed a number of areas, including a main entrance, several offices, a kitchen, a game room, bathrooms, a storage room and a security room. It was recorded from a first-person perspective (i.e., the avatar person was not visible). This person navigated through the different rooms, always starting from the same point on the floor. The person's goal was to find a laptop, which was in one of these rooms. Each room was explored once, and the routes were not repeated except when entering and exiting each room. Throughout the video, several objects were displayed to serve as landmarks. (See Appendix 6 for pretest for valence of selected objects; N=22).

Facial stimuli. The faces used in the emotion categorisation task were taken from the Max Plank Face Database (Ebner, Riediger & Lindenberger, 2010). This comprehensive database consists of two sets of images per individual, depicting six different facial expressions: neutrality, sadness, disgust, fear, anger and happiness. These expressions were presented across three perceived age groups: young, middle-aged, and older, resulting in a collection of 2,052 images. For our study, we selected 90 faces per condition, focusing on neutral, angry, and fearful expressions (Figure 3.1). We selected half male and half female Caucasian individuals, equally distributed in three age categories (N = 30 in each category).

Spatial Navigation tasks. We developed six different tasks to assess the main domains of navigation: landmarks, location, and path. Our tasks were inspired by previous research in navigation and by the conceptual definitions of each domain (e.g., van der Ham, 2020; Wiener et al., 2012; Ruotolo et al., 2018). The tasks were structured as follows: 1) *Landmark recognition* (Figure 3.2). This task primarily taps into the landmark domain. Participants were presented with 15 trials in which they had to identify the object present in the office among three options, ignoring any distractors (chance level: 33%); 2) *Landmark Identification in Context* (Figure 3.3). This task involves the landmark domain but also location egocentric (both what and where). In 10 trials, participants viewed three objects and then indicated which one was present in a room from the office with more contextual details (only one was presented in the video) (chance level: 33%); 3) *Route Ordering* (Figure 3.4). This task investigated the domain of path route knowledge. Participants completed a single trial in which they viewed a series of pictures of the rooms they had seen in the video recording on a screen page, but in a randomised order. They then had to order the pictures by assigning a number from 1 to 10, reproducing the order in which the rooms were seen by the person walking in the video, starting from the entrance and ending where the laptop was found (as each incorrect choice determines whether another choice is also incorrect, since the same number cannot be assigned to two rooms, the chance level was 20%); 4) *Directional pointing* (Figure 3.5). This task again assessed path route knowledge, but with a different approach. It consisted of 16 trials in which participants viewed a series of intersections along the correct route shown in the video from the entrance to the laptop. Two possible directions were indicated by arrows to the left and right, and participants had to click on the chosen arrow for each intersection (chance level: 50%); 5) *Map Representation* (Figure 3.6). This task was related to path survey knowledge. In a single trial, participants were shown three maps depicting the potential floor layout from a bird's eye view. They had to identify the correct map among the options provided (chance level: 33.3%); 6) *Positioning objects on the map* (Figure 3.7). This task tested location strategies with an allocentric frame. In 11 trials, participants were presented with the correct map of the floor and asked to indicate the exact location of different objects between 11 map areas (chance level: 9%). The order of the task presentation was fixed as we tried to minimize the influence of each task on the subsequent one (i.e., positioning objects on the map could not be presented before map recognition).

Additional measures. To describe participant's self-perception of their navigational abilities, participants were administered the Wayfinding Questionnaire (Claessen & de Rooij, 2016). Gender, age, the living area (i.e., rural area, city), GPS navigation apps usage to orient daily and whether they worked or not in an office and, if so, how many hours daily were collected for descriptive purpose (See Appendix 6).

3.2.1.3 Procedure

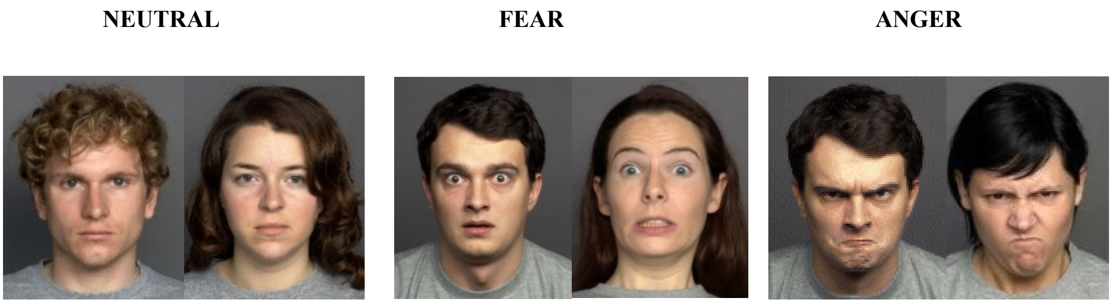
The experiment was conducted online by means of Prolific Platform. Participants were instructed to sit in front of a computer screen and asked to give their informed consent. They were asked to watch the video recording and then complete the tasks described above.

After completing the video recording, participants completed the gender categorisation task, with conditions (neutral vs. fear vs. anger) counterbalanced between subjects. The experimental procedure was identical across conditions. Participants were shown the series of faces (90 trials), 15 male and 15 female, in a randomised order, three times. For each face presented, participants had to indicate the gender of the person depicted by selecting the appropriate male or female button on the screen. Each face was presented alone in the centre of the screen for 1000 ms, and then the choices appeared below each picture. Participants could respond at their own pace. Participants were not explicitly instructed to focus on the emotional content, but rather to perform the gender categorisation task. This task was designed to indirectly engage participants in emotion processing and to influence their subsequent task performance (see previous chapter). Finally, they were required to answer each question and were notified if they skipped a question (Figure 4). Finally, they completed the additional measures and demographics. Participants then completed the navigation tasks in the order in which they were presented in the material section. At last, they were debriefed and paid.

Figure 3.1. a.) Scan with your phone the QR code to see the video recording; b) and examples of male and female expressing fearful, angry, and neutral facial expressions extracted from The Max Plank database (FACES Ebner, Riediger & Lindenberger, 2010). The list of stimuli id used extracted from the FACES are available on OSF. The examples are reproduced with permission by the authors. c) Schematic representation of the procedure.

a. **b.**

SCAN ME



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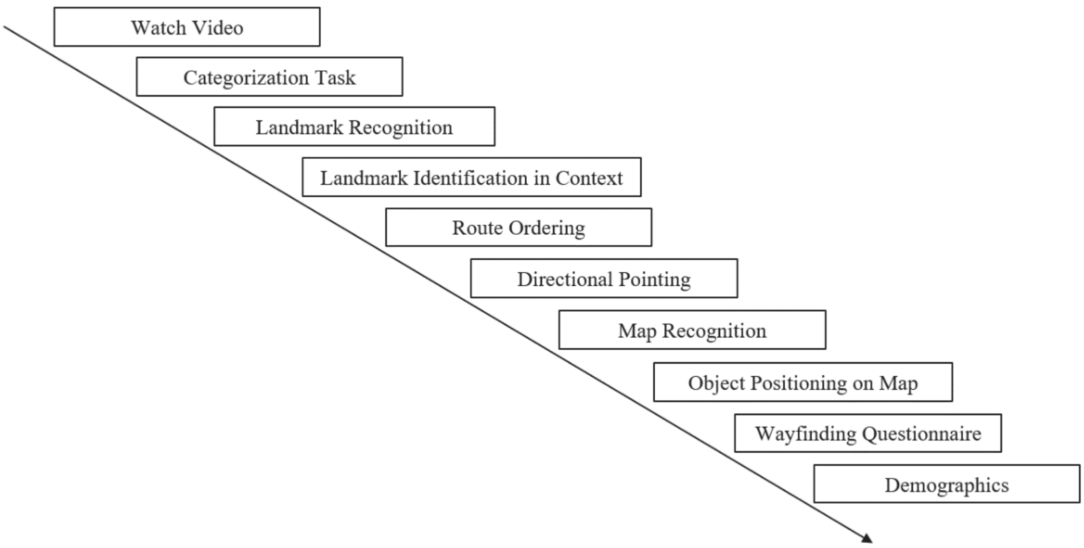


Figure 3.2 First Task: Landmark Recognition: “In the following task you will see 3 objects per question. Please indicate which object you saw in the office among the 3 shown. You have only one choice.”

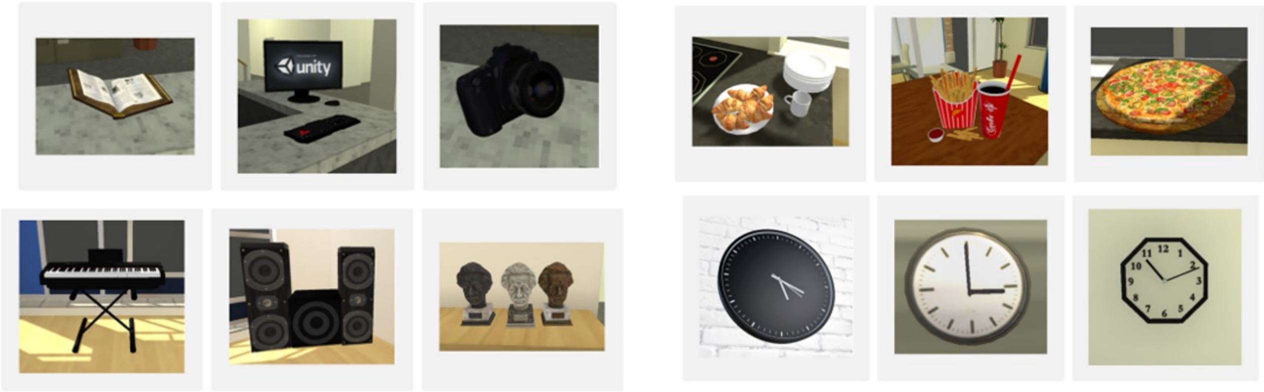


Figure 3.3 Second Task: Landmark identification in context: “In the following task, you will see three objects and one of the rooms. Please indicate which of the objects was present in the room. You have only one choice.”

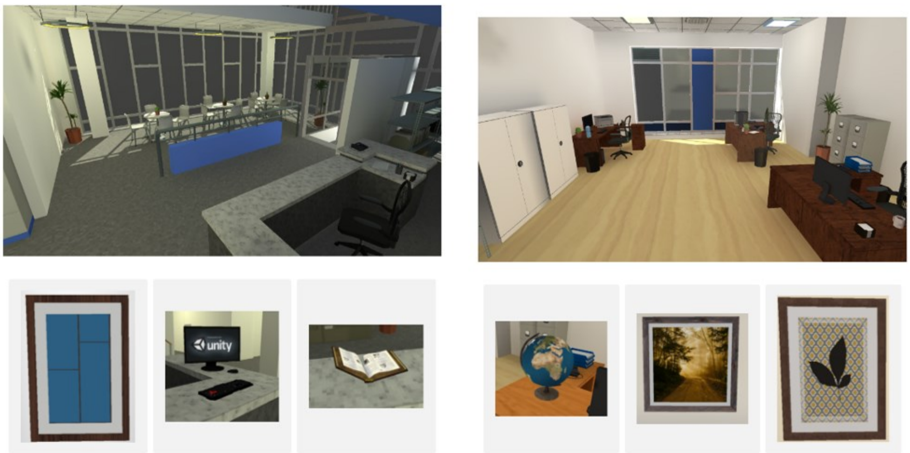


Figure 3.4 Third Task: Route Ordering: “Now you will see all the rooms of the office. Please put in order the images to retrace the route taken by the person walking in the video from the entrance to the ending point. Write in the box on the left a number from 1 to 10 to order the scenes.”

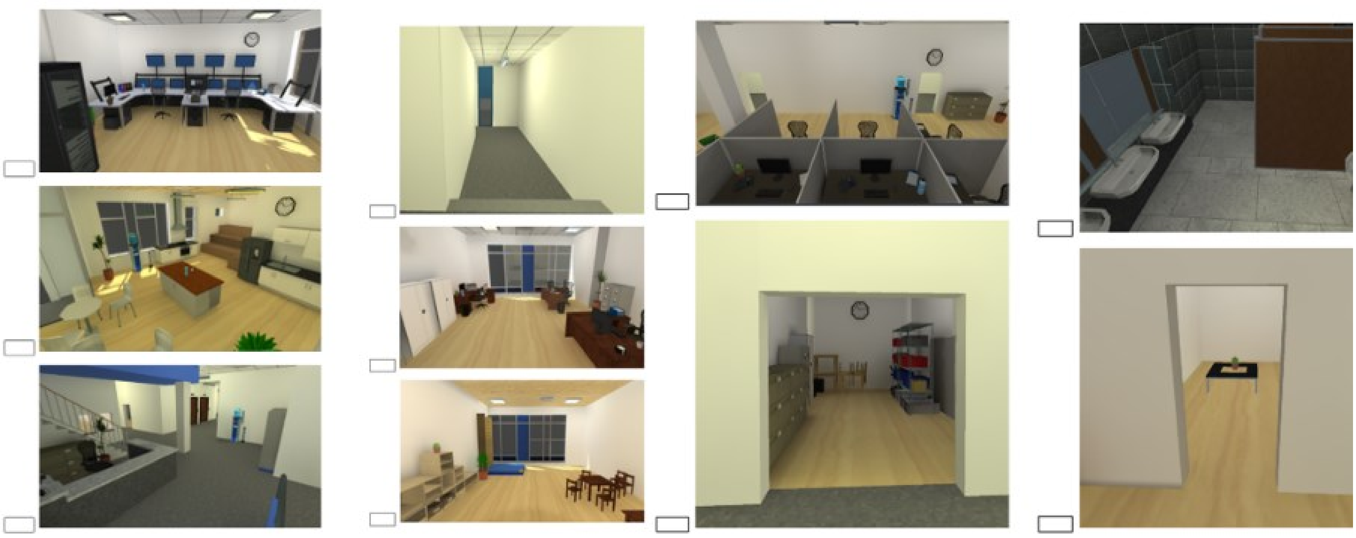


Figure 3.5 Fourth Task: Directional Ponting: "In the following task, you will see a series of intersections. They represent the route taken by the person in the video from the entrance to his laptop. Click either on the left or on the right arrow to indicate the direction the person took. Please click only on the arrows otherwise your choice will not be selected correctly." Possible examples of trials

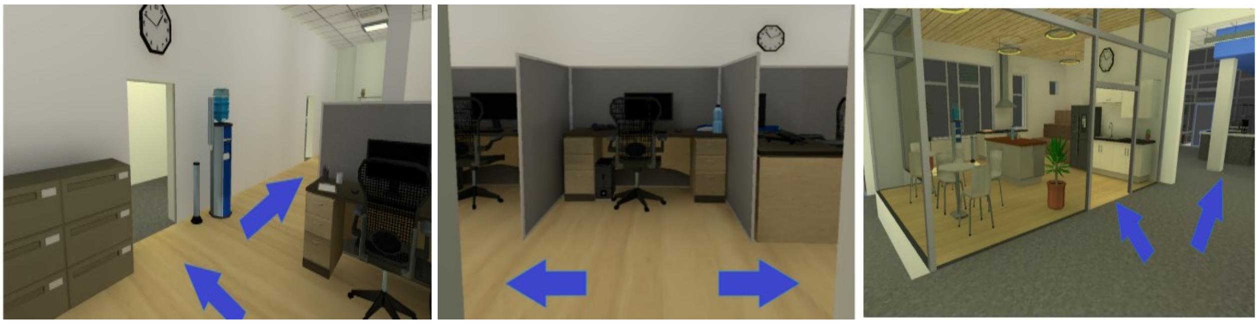
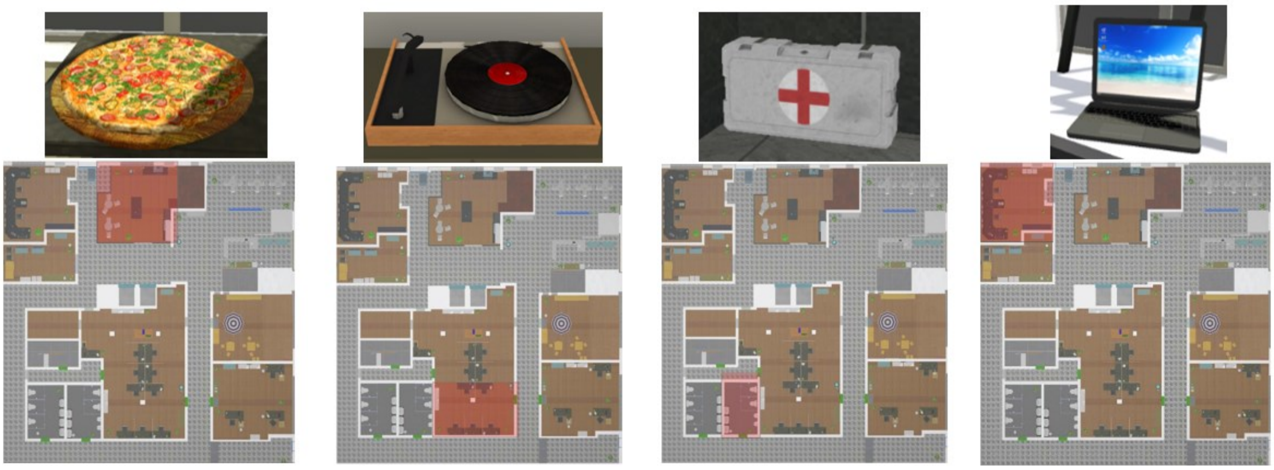


Figure 3.6 Fifth Task: Map Recognition: "Please indicate which of the following maps belongs to the office you have seen in the video." Possible examples of trials

Figure 3.7 Sixth Task: Object Positioning on Map: "Now you will see the correct map of the office: please indicate on the map the position of the following objects. For each object, you can choose only one position by clicking on the map." Possible examples of trials



3.2.1.4 Data Preparation and Statistical Analyses

We first decided to investigate whether male and female performances were better than the chance level in each of our tasks. So, we conducted a series of *t*-tests against the chance level of each task differentiating between the two genders and considering just the condition in which the emotional content of face categorization task was neutral. This analysis told us whether participants were able to complete the tasks with good performances and was a first glimpse into gender differences.

Given the binomial distribution of our dependent variables and that we had multiple observations per participant, we used logistic regression as a generalized mixed model (GMM) to analyse our data. For the map recognition task, which did not have multiple observations, we instead used logistic regression as a generalised linear model (GLM). We analysed the data in R Studio using the packages 'lmerTest', 'emmeans' and 'marginaleffects'. In all cases, the fixed effects consisted of gender (male vs. female), emotion (neutral vs. fear vs. anger) and their interaction. For the GMM, we included as random effects the intercept per participant ID (i.e. representing differences between multiple observations from each participant) and the intercept per trial ID (i.e. identifying differences between trials in each task). For the object positioning task, it was possible to additionally include a more complex random effect, namely a random intercept per trial according to the slope of the emotional condition, a specification that did not converge on all other occasions (see Barr et al., 2013). We first inspected the significance of each effect, that is gender, emotion, and their interaction (in this order). We used simple contrast coding for gender (*Female* = -.5, *Male* = .5) and emotions (*Neutral* = [(-.33, -.33], *Fear* = [.66, -.33], *Anger* = [-.33, .66]). For inspecting interactions, we looked at the differences between the conditions adjusting for multiple comparisons with the Holm-Bonferroni approach. All data and analysis scripts are available at https://osf.io/7u8vx/.

3.4.2 Results

3.4.2.1 Comparison against the Chance Level.

In all measures, participants in the neutral condition performed better than the chance levels (Table 3.1). *Landmark recognition*: Males, $t(76) = 35.24$, $p < .001$, $d = 8.08$, Females, $t(83) = 37.20$, $p < .001$, $d = 8.17$; *Landmark identification in context*: $t(76) = 29.21$, $p < .001$, $d = 6.70$, Females, $t(83) = 22.91$, $p < .001$, $d = 5.03$; *Route ordering*; Males, $t(76) = 7.25$, $p < .001$, $d = 1.66$, Females, $t(83) = 4.86$, $p < .001$, $d = 1.07$; *Directional pointing*: Males, $t(76) = 12.15$, $p < .001$, $d = 2.79$, Females, $t(83) = 17.87$, $p < .001$, $d = 3.92$; *Map recognition*: Males, $t(76) = 11.66$, $p < .001$, $d = 2.67$, Females, $t(83) = 2.88$, $p = .005$, $d = .63$; *Positioning objects on the map*: Males, $t(76) = 16.90$, $p < .001$, $d = 3.88$, Females, $t(83) = 11.14$, $p < .001$, $d = 2.45$.

3.4.2.2 Emotional and Gender Differences.

The results are reported in Table 3.3. No differences due to gender, emotions, or their interaction were found in landmark recognition, landmark identification in context, and directional pointing. A slight male advantage, justified by a significant main effect of gender, was observed in route ordering, but no differences in emotions and its interaction with gender. Notable differences were observed in the last two tasks, map recognition and positioning on the map. For the former, a significant gender main effect was qualified by an interaction with emotions. The interaction told us that while males were outperforming females in the neutral condition, consistent with a male advantage hypothesis in an allocentric location task, the difference was cancelled out when they were exposed to anger and fearful faces.

A similar pattern was observed in the remaining test, positioning on the map of the objects, with a significant main effect of gender and an interaction with emotions. This interaction showed that males were better than females in the neutral and anger conditions, but in the fear condition the difference found in the other conditions was cancelled (Figure 3.8).

Table 3.1. Means and standard deviations (in parenthesis) of each of the six tasks expressed in percentages of success (1-100%) as a function of gender and emotional conditions.

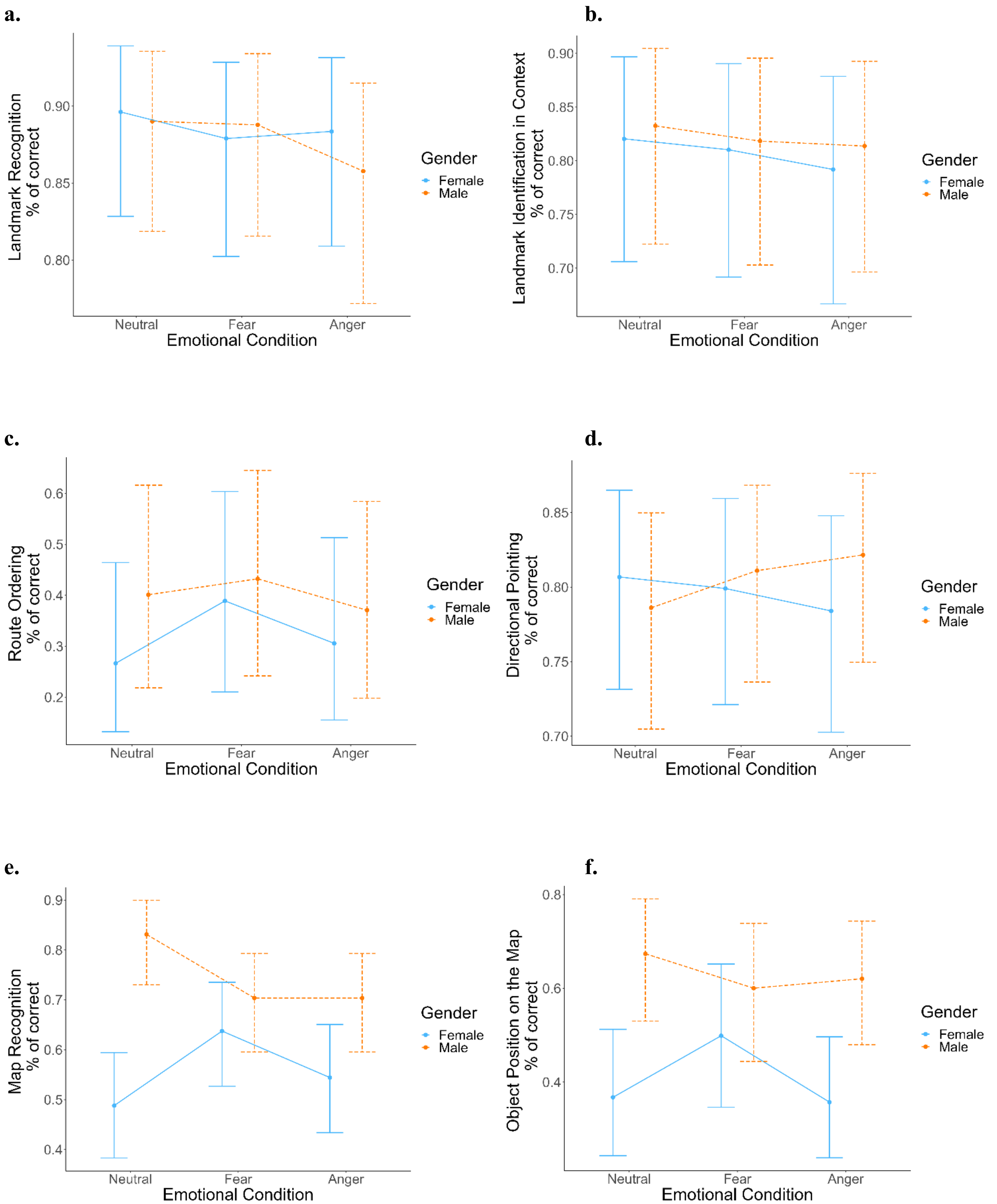
Tasks	*Females*			*Males*		
Emotions	Neutral	Fear	Anger	Neutral	Fear	Anger
Landmark Recognition	83.8 (12.5)	81.9 (13.4)	82.2 (14.6)	83.2 (12.5)	82.6 (14.9)	79.8 (12.8)
Landmark Identification	76.9 (17.4)	76.1 (16.0)	74.4 (15.4)	78.3 (13.6)	76.9 (13.8)	76.4 (16.0)
Route ordering	33.1 (24.7)	41.3 (28.7)	35.6 (24.1)	41.8 (26.4)	44.1 (26.6)	40.1 (24.2)
Directional Pointing	76.7 (13.7)	75.7 (18.1)	74.7 (12.6)	74.5 (17.7)	77.1 (14.1)	78.1 (14.3)
Map Recognition	48.8 (50.3)	63.8 (48.4)	54.4 (50.1)	83.1 (37.7)	70.4 (45.9)	70.4 (45.9)
Positioning on Map	40.8 (26.2)	50.0 (27.8)	39.9 (26.1)	62.3 (27.7)	56.6 (29.0)	57.5 (29.5)

Note: chance levels were 33% for landmark recognition, identification in the context, and map recognition; 50% for directional pointing; 20% for route ordering; 9% for object positioning on the map.

Table 3.3. Deviance analysis and results of the generalized linear mixed model for each of the dependent variables (DV) and independent variables (IV) reporting the likelihood ratio, its degrees of freedom, and its *p*-values, as well as the *Z*-tests on each effect, its *p*-values, and the odds ratios (OR).

DV	*IV*	*χ2(df)*	*Z*	*p*	*OR*
Landmark Recognition	Gender	.46 (1)	-.68	.499	.93
	Emotions	2.87 (2)		.238	
	Fear vs. Neutral		-.78	.724	.91
	Anger vs. Neutral		-1.69	.273	.81
	Fear vs. Anger		.91	.724	1.12
	Gender X Emotions	1.60 (2)		.449	
	Neutral: M vs. F		-.36	.722	.94
	Fear: M vs. F		.49	.627	1.09
	Anger: M vs. F		-1.31	.191	.79
Landmark Identification	Gender	.89 (1)	.95	.345	1.10
	Emotions	1.72 (2)		.423	
	Fear vs. Neutral		-.70	.972	.92
	Anger vs. Neutral		1.31	.570	.86
	Fear vs. Anger		.62	.972	1.07
	Gender X Emotions	.13 (2)		.936	
	Neutral: M vs. F		.50	.620	1.09
	Fear: M vs. F		.32	.751	1.05
	Anger: M vs. F		.83	.408	1.15
Route Ordering	**Gender**	**5.49 (2)**	**2.34**	**.019**	**1.43**
	Emotions	4.10 (2)		.129	
	Fear vs. Neutral		1.83	.201	1.41
	Anger vs. Neutral		.17	.866	1.03
	Fear vs. Anger		1.66	.201	1.37
	Gender X Emotions	1.42 (2)		.492	
	Neutral: M vs. F		**2.29**	**.022**	**1.84**
	Fear: M vs. F		.67	.500	1.20
	Anger: M vs. F		1.09	.274	1.34
Directional Pointing	Gender	.50 (1)	.70	.481	1.06
	Emotions	.27 (2)		.872	
	Fear vs. Neutral		.49	1,00	1.05
	Anger vs. Neutral		.40	1.00	1.04
	Fear vs. Anger		.10	1.00	1.01
	Gender X Emotions	2.88 (2)		.237	
	Neutral: M vs. F		-.84	.402	.88
	Fear: M vs. F		.50	.618	1.08
	Anger: M vs. F		1.44	.120	1.27
Map Recognition	**Gender**	**19.73 (1)**	**4.36**	**< .001**	**1.95**
	Emotions	1.16 (2)		.558	
	Fear vs. Neutral		-.23	.817	.94
	Anger vs. Neutral		-1.01	.628	.78
	Fear vs. Anger		.82	.123	1.21
	Gender X Emotions	**7.65 (2)**		**.022**	
	Neutral: M vs. F		**4.38**	**< .001**	**5.16**
	Fear: M vs. F		.89	.372	1.35
	Anger: M vs. F		**2.07**	**.038**	1.99
Positioning on Map	**Gender**	**37.10 (1)**	**6.09**	**< .001**	**2.51**
	Emotions	1.65 (2)		.437	
	Fear vs. Neutral		.59	.940	1.12
	Anger vs. Neutral		-.72	.940	.87
	Fear vs. Anger		1.29	.594	1.28
	Gender X Emotions	**5.95 (2)**		**.051**	
	Neutral: M vs. F		**4.85**	**< .001**	**3.56**
	Fear: M vs. F		1.58	.11	1.51
	Anger: M vs. F		**4.12**	**< .001**	**2.94**

Figure 3.8. Performances for the six navigational tasks expressed in percentages of success in function of gender and the emotional conditions between subjects. The light blue line represents female participants, and the red line represents male participants. Bars represent standard error around the means. The tasks represented are: a. Landmark Recognition; b. Landmark Identification; c. Route Ordering; d. Directional Pointing; e. Map Recognition; f. Object Positioning on Map.



3.4.3 Discussion

The influence of emotional processing on navigation has hardly been investigated (Pessoa, 2012; Burles et al., 2020). Navigation relies on several domains that, to our knowledge, have been studied independently of emotional factors (van der Ham et al., 2020). A fundamental emotional stimulus that drives human behaviour is the human face, especially when it conveys strong emotions such as fear or anger (Ekman & Rosenberg, 2005). In this experiment, we investigated the influence of facial emotion processing on three domains of navigation: landmark, location, and path knowledge. Participants were asked to watch a recording of a person walking in a virtual environment with the goal of finding an object. They were asked to remember and pay attention to the details of the route taken. Then they were exposed to one of three emotional conditions, i.e. they took part in a gender categorisation task with 90 faces showing either neutral, fearful, or angry expressions. Finally, they completed in six navigation tasks related to the route information and landmarks in the recording. We also examined differences in performance based on the participants' gender, as previous research has highlighted the role of this factor.

Importantly, we found evidence for an influence of negative emotions on performance in some domains. These results partially replicate our findings reported in Chapter 2 but extend them beyond purely behavioural outcomes to more cognitive domains of spatial navigation. To some extent, the classification of outcomes as behavioural rather than cognitive is a matter of perspective, but both are important in describing the nature of a process. For example, egocentric referencing involves using one's own body as a reference point, whereas allocentric referencing uses external cues in the environment. The use of these strategies can be measured both as behavioural outcomes, i.e. measuring the observable actions of participants in navigating space, and as cognitive outcomes, emphasising the mental processes involved in selecting and using these strategies for spatial orientation. In this experiment, we have emphasised the cognitive side of our measures, thus providing complementary key findings to the behavioural outcomes of the previous chapter.

We found that when there was no emotion manipulation (neutral condition), both males and females performed better than chance on all tasks. Thus, it appears that participants were able to learn valuable information from observing someone else navigating an environment, and that our tasks were effective in measuring their ability to analyse the route and its information. In addition, we found evidence of gender differences (i.e., male advantage) in one of the route knowledge tasks (route ordering), which is consistent with our hypothesis (Hp1) and with van der Ham and colleagues (2020). We found no difference in the landmark-based measures, which could mean that female performance was better than in the other tasks and reached the level of males (Sandstrom et al., 1998). However, we also found some unexpected inconsistencies, as gender differences only occurred in one of the two route knowledge tasks. The two tasks were different in nature and may have been approached differently by the participants: route ordering may require a higher degree of abstraction than directional pointing, thus, increasing the difficulty of the task at hand. Gender differences are particularly observed when tasks are visuo-spatially demanding (Coluccia & Louse, 2004), and it makes sense that these differences were observed in the more demanding task. Interestingly, the same reasoning might apply to explain why van der Ham et al. found such differences in their path route task, which is very similar to our direction pointing task: on some trials, they allowed participants to choose the direction between three possible options, rather than between two directions as we did, and their choice may have increased the difficulty of the task and exacerbated the gender differences, unlike ours.

We also observed gender differences in the neutral conditions of the location task with an allocentric frame (object positioning on the map), which is consistent with the trend found by van der Ham et al. (2020) and research suggesting that males are advantaged in this type of task (Chai & Jacobs, 2010; Saucier et al., 2002). In addition, we observed the same for path survey knowledge (map recognition), which may be consistent with the theory of gender differences (Castelli et al., 2008), but not with van der Ham et al.'s (2020) findings. Again, a comparison of our tasks with theirs may be fruitful in understanding the differences in results. van der Ham et al.'s path survey task was designed to test the ability to identify the two closest landmarks (out of a set of three) while imagining the distance of the objects from a bird's eye view. Instead, in developing our measure, we relied on a definition of survey knowledge that focuses on "the construction of a cognitive map of the environment, a map that 'integrates' the different routes by means of the relationships between the different locations" (Castelli et al., 2008, p. 1648). Thus, we thought that distinguishing between different but similar maps of the ground used for navigation, with landmark positions visible from above like from a bird's-eye view, might have been an adequate operationalisation of the conceptual definition of path survey knowledge. Finally, our results may differ from theirs because we tested a different facet of path survey knowledge than theirs, which instead relied heavily on landmark specific information (a possibility also suggested by the authors, van der Ham et al., 2020, p. 9). Future studies should address the differences between our tasks and theirs.

We hypothesised that only fearful (and not angry or neutral) emotional expressions would be effective in modulating the outcome of our tasks (Hp2), and we found this result in the path survey task (i.e. map recognition), always modulated by gender differences (Hp3). Males who outperformed females in the neutral and angry conditions did not differ from them in the fearful condition. However, such a difference can be explained by two processes together: males performed worse when exposed to fear, but females also performed better, as the descriptive pattern suggests. The lack of difference is only present in the fear condition, which means that the difference observed in the neutral or anger conditions is neutralised by exposure to fear. A parallel result was observed for the location task (object positioning), where the difference between males and females was bigger in the neutral condition, but the difference was not significant in the fear and anger conditions.

Ultimately, we previously found that females were unaffected by exposure to either fear or anger; however, in these tasks, females improved in navigation tasks after exposure to negative emotions, fear or anger compared to neutral ones. This is a new and unexpected finding. Males and females have been found to differ not only in their navigation strategies, but also in how their memory systems deal with threatening stimuli, both from a behavioural and neurophysiological perspective (Tronson & Keiser, 2019). We might suggest that the differences observed here are due to differences between the genders in how they manage WM resources, which are essential for both navigation and emotion processing of faces (Baddeley et al., 2012; Brown & Chrastil, 2019). WM is essential for the use of survey knowledge and allocentric navigation, especially in its spatial and visual components (Aagten-Murphy & Bays, 2019; Wen et al., 2011). However, the same cognitive resources may be required for processing negative emotions from faces (Berggren et al., 2017; Curby et al., 2019; Lindström & Bohlin, 2012; Shields et al., 2017). If females are better than males at managing WM resources for emotional face processing (e.g., Olderbak et al., 2019), they may have had more resources left over for the subsequent tasks. In addition, females tend to use a greater variety of emotion regulation strategies than males (Goubet & Chrysikou, 2019), which may have helped to counteract any emotional contagion on their mood due to repeated exposure (Elfenbein et al., 2014).

This cannot be completely ruled out in our data. Finally, the positive trend in female's performance due to exposure to negative stimuli is perhaps surprising, but it is not inconsistent with previous findings on WM tasks (e.g., Lindström & Bohlin, 2011) and object location tasks (although emotionality was manipulated in relation to the object to be remembered and not to an irrelevant stimulus, Costanzi et al., 2019). Furthermore, gender and emotion differences were observed in the tasks that might require a higher degree of WM resources, i.e. those from an allocentric perspective and those related to path survey knowledge (van der Ham et al., 2020; Castelli et al., 2008; Coluccia & Louse, 2004). This could also be the reason for the observed differences. Therefore, our findings shed light on potential and relevant gender differences in spatial navigation and emotion influence that could be further investigated from a perspective related to cognitive resource management, explicitly addressing the role of WM.

Our study is not without limitations. First, in our experiment, we used a relatively small virtual reality environment (i.e., an office) within a building, which has the advantage of being realistic and including several everyday objects as landmarks. However, navigation may also and frequently occur in large and outdoor environments, and navigation strategies and mental maps may differ accordingly (Ekstrom & Isham, 2017). Future research should replicate our findings in different types of environments. Overall, this experiment helped us to answer our fourth open question and to complement the findings of the previous chapter. The next chapter will address gender differences in emotion processing during VSWM, which may help explain some of the findings observed here and in Chapter 2.

CHAPTER 4:

THE EFFECT OF NEGATIVE FACIAL PROCESSING ON VISUOSPATIAL WORKING MEMORY

CHAPTER 4: THE EFFECT OF NEGATIVE EMOTIONAL FACES ON VSWM

In this chapter, we tested the possibility that visuospatial working memory (VSWM) performance might be influenced by exposure to negative facial emotions. Specifically, we measured VSWM performance before and after exposure to neutral, fearful, or angry facial expressions. We also investigated a potential mechanism of their influence on VSWM by quantifying the cognitive load imposed by emotion exposure while performing a task that also engages VSWM resources.

4.1 Introduction

Mnemonic information is fundamental to the management of our daily lives: some memories are long-lasting and stored in our brains for long periods of time to be retrieved when needed, while other information is encoded, processed and used immediately (Baddeley, 2012). The latter is thought to be mainly used by what is known as working memory (WM), a multi-component memory function with limited processing resources and storage capacity. When the information is spatial and/or visual in nature, its processing relies more specifically on VSWM (or visuospatial sketchpad; Baddeley & Hitch, 1974; Chai et al., 2018). Few studies in this area have focused on the interplay of emotional and cognitive factors for VSWM performance, and even fewer on the influence of facial emotional expressions on VSWM performance. Therefore, in this study, we investigated the relationship between facial emotional processing and visuospatial working memory performance, as it may play a crucial role in facial processing, recognition, perception, attention allocation, and memory formation (Luck & Vogel, 2013). Understanding their implications may provide insights into the mechanisms underlying face processing abilities and related cognitive processes.

Visuospatial working memory has been introduced as a system of limited capacity that is helpful in managing stimuli for a task at hand (Baddeley, 2012; Cowan, 2011; Hardman & Cowan, 2015). One potential distinction between spatial and visual working memory is that the former is associated with elaborating the location of an object ('where') and the latter with elaborating its identity ('what'; Darling et al., 2007). Such a distinction mirrors that of the dorsal and ventral pathways in our brain (Cloutman, 2013). Some theories have suggested a separation of the visual and spatial components, and, thus, separate resources devoted to each (e.g., Baddeley, 2007; Baddeley & Logie, 1999; Della Sala, et al., 1999). Another perspective suggests that there is a shared pool of resources and that the two components are linked (Vergauwe et al., 2009). VSWM plays an important role in face processing because it is involved in the storage and manipulation of visual information, including facial features and the spatial relationships between them (Baddeley, 1992). This cognitive function aids face recognition and memory by storing and maintaining visual representations of facial features (Bruce & Young, 1986). It allows individuals to compare incoming visual stimuli with stored representations to accurately identify familiar faces. As face processing involves analysing the spatial configuration of facial features such as eyes, nose and mouth (Maurer et al., 2002), VSWM helps to encode and maintain the relative positions of these features, which is crucial for recognising faces under different viewing conditions and angles (Haxby et al., 2000). In addition, visuospatial working memory influences how we perceive facial expressions and emotions by integrating spatial information from different parts of the face (Adolphs, 2002). Remembering the spatial relationship between the eyes and mouth can facilitate the recognition of emotions such as happiness or sadness (Haxby et al., 2000). In addition, VSWM guides attention during face processing by maintaining relevant spatial information (Klin et al., 2002).

VSWM allows focus on specific facial features or regions of interest, facilitating detailed analysis and recognition of faces in complex visual scenes. VSWM also contributes to the formation and retrieval of face memories (Barton et al., 2003), allowing individuals to maintain a mental representation of a face for a short period of time, which is essential for tasks such as following a conversation in a group or identifying someone in a crowd. Furthermore, the construction of composite images of faces from memory (Frowd et al., 2008) allows individuals to combine stored visual information about facial features to create a coherent representation of a face, which is useful in forensic settings or eyewitness testimony. Deficits in VSWM can impair face processing abilities, leading to difficulties in recognising faces, interpreting facial expressions and maintaining social interactions (Boucher et al., 2012). Such deficits are common in neurodevelopmental disorders such as autism spectrum disorder and neurodegenerative diseases such as Alzheimer's disease.

The visuospatial cognitive load may differ in tasks involving the detection and recognition of fearful versus angry faces. Fear and anger are distinct emotional expressions characterised by different facial configurations (Ekman & Friesen, 1975). Fear is typically associated with widened eyes and raised eyebrows, whereas anger is often associated with narrowed eyes and a furrowed brow. The processing of these facial expressions requires different levels of visuospatial cognitive load due to differences in the complexity of the spatial configuration of facial features. Thus, fearful expressions may produce stronger visuospatial memory traces than angry expressions (Buchanan & Adolphs, 2002). Retrieval of these memories may therefore place different cognitive demands on visuospatial working memory. Fearful expressions may attract attention more easily due to their evolutionary importance as signals of potential threat (Öhman & Mineka, 2001). As a result, processing fearful faces may place a higher cognitive load on visuospatial attention than processing angry faces. Furthermore, fear and anger recognition relies on the integration of spatial information from different facial features (Calvo & Lundqvist, 2008). The visuospatial cognitive load may vary depending on the salience and distinctiveness of the spatial cues associated with each emotion. Fearful facial expressions may involve subtle changes in eye widening and mouth shape, requiring precise visuospatial processing for accurate recognition. Finally, differences in exertional load may affect the encoding and retrieval of fearful and angry faces in memory.

In particular, fearful stimuli tend to capture attention and interfere with the allocation of attentional resources to other tasks (Vuilleumier, 2005). Furthermore, fearful faces have been found to cost memory performance compared to neutral or happy faces, disrupting visual working memory (VWM) performance, the visual component of VSWM, and producing longer response times but equivalent accuracy compared to faces with neutral expressions (Kensinger & Corkin, 2003). Curby et al. (2019) found that fearful faces impaired VWM performance more than neutral faces when given ample time (4000 ms) compared to short time (1000 ms) to respond to a delayed match-to-sample probe recognition task (see also Curby & Gauthier, 2007). Compared to fearful faces, angry faces appear to attract less attention (Engen et al., 2017; Vuilleumier, 2005), but are more resistant to attentional disengagement than happy faces, thus increasing responses in a primary task when acting as exogenous cues or increasing search time in a visual search paradigm (Becker et al., 2019; see also Feldmann-Wüstefeld et al., 2011). Davis et al. (2011) compared fearful and angry faces in a memory test and showed that memory for angry faces was enhanced compared to fearful faces, but fearful faces enhanced memory for contingent stimuli (i.e., neutral words) compared to angry stimuli.

This finding suggests that fearful faces increase diffuse attention to the surrounding context, possibly to identify an unknown source of threat, whereas angry faces focus attention on themselves because they are the source of threat. Therefore, the two stimuli may impose different resource costs, and according to Curby et al. (2019), the costs on VWM are higher for fearful faces than for angry faces (Sessa et al., 2011; Stout et al., 2013; importantly, all these studies used task-irrelevant facial expressions; see Gambarota & Sessa, 2019 for a review). As argued by Gambarota & Sessa (2019), it seems that methodological differences may account for the different results obtained so far, as Curby et al. (2019) obtained detrimental effects using a task that relies less on the spatial component of VSWM (i.e., a delayed match-to-sample probe detection task), while Sessa et al. (2011), who used a supposedly more 'spatial' change detection task, obtained opposite results. Thus, the evidence is mixed and requires further investigation.

Furthermore, none of these studies examined whether the elaboration of emotional faces in a VSWM task consumes resources that are also useful for a subsequent VSWM task. Previous findings suggest that working memory capacity is impaired by emotional (as opposed to neutral) stimuli (Garrison & Schmeichel, 2019). If emotional faces are attention-grabbing and influential stimuli, their effect on working memory may extend beyond the immediate presentation. To our knowledge, there is no evidence for this. Some studies have tested the assumption that when a task affects working memory, a delay is needed to recover before being tested again, otherwise performance will be suboptimal due to depleted cognitive resources (e.g., Chen & Kalyuga, 2021; Sweller et al., 1998, 2011). For example, Schmeichel (2007) conducted a series of experiments in which undergraduate students performed a self-control task that was expected to deplete working memory. After completing the task, working memory was assessed. The results showed that the most difficult condition increased cognitive effort and depleted working memory (but see Healey et al., 2011, who found an effect due to stimulus similarity rather than resource depletion). It is not implausible to suggest that engaging in a VSWM task based on the identity recognition of emotional faces (i.e., emotions are irrelevant to task performance) might consume more cognitive resources than when neutral faces are used, because participants might want to control their attention to the irrelevant but salient emotional content of the faces in order to complete the task (Schmeichel & Baumeister, 2010). Thus, resources that might be useful for a subsequent VSWM task might ultimately be depleted if emotions were particularly salient in the first task.

Specifically, the consolidation phase of VSWM can be disrupted by visual processing and the maintenance of spatial processing can be disrupted during visual search tasks (Anderson et al., 2008; Oh & Kim, 2004). According to this and other perspectives, working memory capacity is closely related to the attentional resources that manage the updating and storage of information. (Barrouilet et al., 2007; Cowan, 2011). Thus, attentional stimuli are thought to steal resources from the VSWM. The human mind is well equipped to detect emotion-related stimuli, often in order to prevent undesirable outcomes due to missing important and vital information opportunities or threats (Öhman, 2002; Vuilleumier, 2002). The facial expression of others is an example of stimulus that is relevant for our interactions that might disrupts the processing of other stimuli in the same environment, attracts more attentional resources than neutral stimuli due to its higher adaptive salience (Palermo & Rhodes, 2007; Vuilleumier et al., 2001; Vaish et al., 2008), and is identified with greater accuracy and speed compared to other changing objects in the environment (Jenkins et al., 2005; Reinders, den Boer & Büchel, 2005). In particular, fear and anger may be relevant because of their relationship to fight-or-flight responses (Ekman & Cordaro, 2011; Palermo & Rhodes, 2007).

Fearful faces in particular can attract and capture our attention and visual perception due to their configurational features influencing working memory consequently (Lepsien & Nobre, 2006). Faces that convey fear communicate vulnerability or submission to others and signal a need for protection or help. As a result, fear elicits empathetic, caring or supportive responses from others (Ishikawa et al., 2021; Phelps et al., 2006). In contrast, anger prepares individuals for confrontational and intrapersonal behaviours by mobilising energy to approach and overcome obstacles or threats. Perceiving anger in others can lead to aversive and avoidant behaviours (Seidel, 2010).

Facial configurational processing, indeed, involves integrating facial features to recognize faces, relying on spatial relationships between features rather than individual features themselves (Bruce & Young, 1986). While it engages visuospatial processes, it may not be classified as a high visuospatial working memory load task similar to mentally manipulating complex spatial information (Maurer et al., 2002). The level of visuospatial working memory load in facial configurational processing can vary based on task complexity and individual differences. Expressions of fear and anger can indeed influence different stages of facial processing and apparently the recruitment of VSWM resources. Understanding these differences provides insights into the cognitive mechanisms underlying the perception and interpretation of emotional facial expressions. However, individual variability in visuospatial cognitive abilities may influence how fear and anger expressions are processed. For instance, one important difference is due to the gender/sex of the individual. Males have been found with higher VSWM capacity (Gonzales-Garrido et al., 2013; Voyer et al., 2017; Zilles et al., 2016). However, females are usually better at emotion recognition and regulation (Hoffman et al., 2010; Kret & de Gelder, 2012; Saylik et al., 2018; but see Fischer et al., 2018). Thus, males might be better in VSWM tasks, but not when processing also emotional stimuli, a condition that should reduce the difference between the two genders (see also our previous chapters).

Moreover, some neurological differences might also account for the discrepancies. Males show right hemispheric dominance for spatial processing compared to females who were found a bilateral activation (Munion et al., 2019; Coluccia & Louse, 2004). Specifically, hemispheric specialisation in spatial representation has been observed, with the left cerebral hemisphere specialising in categorical spatial representations and the right cerebral hemisphere specialising in coordinate spatial representations (Kosslyn et al., 1989; Laeng, 2013; Jager & Postma, 2003). In addition, several structures in the right hemisphere are activated for negative valence stimuli or stimuli associated with avoidance or withdrawal behaviour (Davidson & Tomarken, 1989). Eventually, compared to females' bilateral activations for such functions, males might show a greater decline in their VSWM abilities after exposure to fearful faces because the same right areas are used to engage in two different functions (i.e., visuospatial vs. emotional information processing).

4.2 EXPERIMENT 5: The Effect of Negative Facial Emotion Processing on Visuo-Spatial WM

The present study investigated the possibility that emotional faces, especially fearful and angry faces, affect performance in the current and subsequent VSWM tasks. The study investigated whether visuospatial resources required for one task could be subtracted when performing another visuospatial task using emotional faces. Participants' VSWM abilities, assessed with a backward Corsi block tapping task (CBT), were compared before (i.e. baseline) and after a delayed non-match-to-sample task (DNMS) modified to display either fearful, angry, or neutral facial expressions. We chose these two tasks because they are well-established tools for measuring working memory from a spatial and visual perspective (Elliot & Dolan, 1999; Carretié et al., 2013; Kessels et al., 2008).

In contrast to previous research, we did not test the influence of emotional faces solely on the task in which they were presented (e.g., Curby et al., 2019; Sessa et al., 2011). Instead, we used three sequential tasks to test whether, compared to baseline (CBT-Time 1), we could observe an influence on subsequent performance (CBT-Time 2) that could ultimately be explained by the processing of emotional faces (neutral vs. fearful vs. angry) in another VSWM task (DNMS). Consistent with previous research in VSWM, the faces presented in the DNMS were task-irrelevant (see Gambarota & Sessa, 2019).

The evidence for impairment or enhancement of VSWM by negative stimuli is rather mixed (see Curby et al., 2019; Sessa et al., 2011; Gambarota & Sessa, 2019). We decided to adopt a DNMS, which has some similarities with Curby et al. (2019). However, as argued by Gambarota and Sessa (2019), we took care to increase the relevance of the spatial component of WM (i.e., items changed position on the screen from trial to trial) and the visual component of WM (i.e., identifying a different face among a set of seven faces instead of an array of five faces as in Curby et al., 2019). Therefore, due to the theoretically high complexity and demands of this task, which is more in line with Curby et al. (2019) than Sessa et al. (2011), we expected that negative emotional stimuli would impair VSWM more than neutral stimuli (Hp1). This effect might depend on the type of emotion considered. For the present situation, we propose that if fearful facial expressions would require more VSWM resources in the DNMS, there would be fewer resources available for the subsequent VSWM task. In other words, because of the high demands on the limited VSWM resources in the DNMS, performance in CBT-T2 should be impaired. Fearful faces may be more effective than angry or neutral faces (see Curby et al., 2019) in impairing both DNMS scores and times (Hp2), and consequently affect CBT performance more than angry or neutral faces (Hp3).

Previous research on working memory and emotion perception has yielded conflicting results, which may also be due to the fact that they did not consider gender differences (with the exception of Gonzales-Garrido et al., 2013). Gender differences play a fundamental role in visuospatial working memory abilities and emotion processing (Saylik et al., 2018; Voyer et al., 2017). Although the difference may be small, males are expected to outperform females in VSWM tasks (e.g., Gonzales-Garrido et al., 2013; Voyer et al., 2017; see also our previous chapters) prior to any emotional exposure (Hp4), as neuroscience studies suggest VSWM-specific activations that may favour males over females in such tasks (Zilles et al., 2016). Females, on the other hand, are often better at emotion recognition and regulation than males (Hoffman et al., 2010; Kret & de Gelder, 2012; Montagne et al., 2005; Saylik et al., 2018; but see Fischer et al., 2018), and this may allow them to better control the influence of emotions on their performance, modulating the load of facial emotions on DNMS and the transfer to the subsequent CBT-T2.

Even though males are often less accurate and sensitive in labelling facial expressions, they have shown to be more responsive to threatening cues, even when they are subtle and ambiguous (Fischer, Kret & Broekens, 2018; Montagne et al., 2005). Thus, the detrimental effect of negative emotions may affect men more than females (Hp5). These gender differences would be consistent with those in our previous chapters. As our expected results could be related to the strain on the limited VSWM resources, we examined the relationship between performance on the DNMS, which should vary according to the emotion manipulation, and the subsequent CBT. Thus, performance on the DNMS should be correlated with performance on the CBT, especially when fearful faces were presented (Hp6).

4.2.1 Method

The design of our study was a 3 (emotion: neutral vs. fearful vs angry faces) x 2 (gender: female vs. male) x 2 (CBT: T1 vs. T2) mixed design. Emotional conditions (i.e., face expressions in the DNMS) and gender were between subject's factors while the CBT times (T1 vs T2) was varying within-subjects.

4.2.1.1 Participants

We calculated the sample size based on an a priori power analysis conducted on MorePower (Campbell & Thompson, 2012). The power analysis on a 2x3 factorial ANOVA targeting the interaction between gender and emotions with DNMS performance as dependent variable, and that on a 2x2x3 mixed ANOVA targeting the three-way interaction including the factor time with CBT performance as a dependent variable, both suggested to collect 324 participants to find a medium-to-large target effect (Cohen, 1988) of η_p^2 = .03 (Cohen's f = .18) with power = .80 and alpha = .05. Accordingly, we collected 326 participants, but two participants were excluded because did not report their gender, leaving a sample of 324 participants (171 males, M_{age} = 39.10, SD_{age} = 10.95; 153 females, M_{age} = 39.18, SD_{age} = 10.93). About fifty participants were assigned to each condition (Males: *Neutral* N = 54, *Fear* N = 58, *Anger* N = 59; Females: *Neutral* N = 45, *Fear* N = 57, *Anger* N = 51). We reached participants through Prolific Academic, and we paid them £9.00/hour (£3 for 20 minutes of experiment). To address limitations associated with online studies, we implemented several precautions by adhering to exclusion criteria, including neurological conditions, mild cognitive impairment or dementia, colour blindness, and autism spectrum disorder. To mitigate bias stemming from a single population during data collection (e.g., young students at a university in a large city), we aimed to recruit participants worldwide limiting it to English speakers aged 18 to 60 to avoid discrepancies in results due to natural declines in spatial functionality with aging (Cognè et al., 2017).

The study was approved by the Committee for Research Evaluation (CRIP) of the Department of Psychology of the University of Milan-Bicocca (RM 2020-366). All participants received written informed consent and were treated in accordance with the Declaration of Helsinki. Participants were paid in exchange for their participation on Prolific Platform.

4.2.1.2 Materials

Backward Corsi Block Tapping Test (CBT). The task involved repeating in the correct backward order a sequence of up to nine identical blocks (Kessels et al., 2008). We used the online version of the test (Borchert, 2023; Figure 4.1a). On each trial, 9 blue squares (also called blocks) were placed on the screen and lit up in a pre-determined order (constant across participants). The participants were asked to click on the blocks with the left mouse button in the reverse order. The length of the sequence started at level 2, with only two blocks in sequence to remember, and could go up to level 9, with a sequence of nine blocks to remember. Each sequence was repeated twice. If participants failed to reproduce the block-sequence twice in the same level, the task was interrupted. The task took about 5 minutes to complete. The complexity of the task increased as the sequence length increased, challenging the individual's VSWM capacity. The test was scored based on the number of block sequences that the participant could reproduce in the correct order (i.e., span length). We calculated the CBT score following the guidelines of Kessels et al. (2000, 2008), i.e., the product of the span length and the number of trials correctly recalled. The complete task would require the completion of 16 consecutive trials (i.e., a span length of 9).

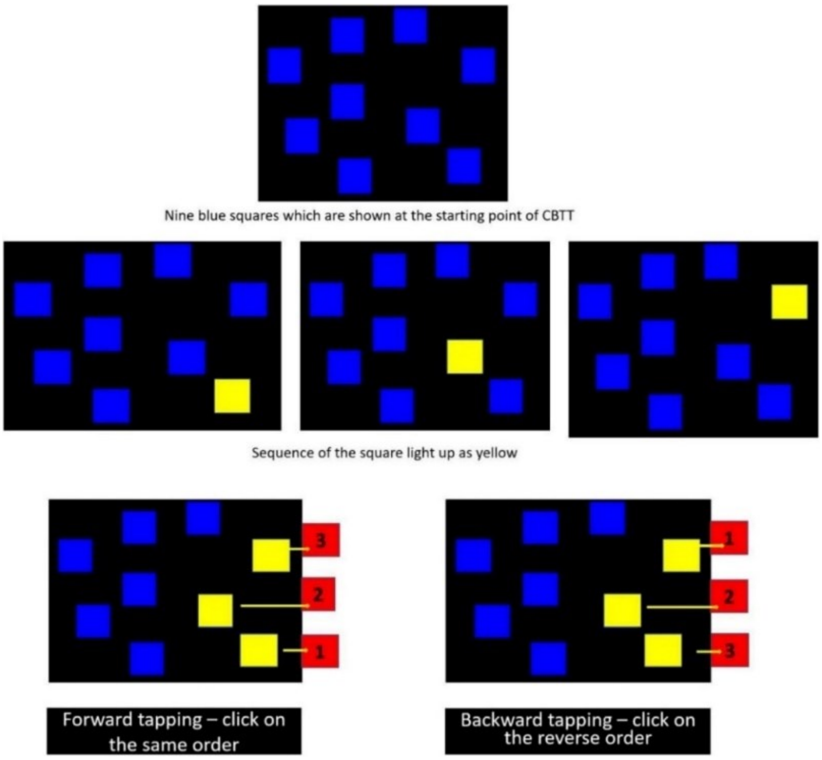
Delayed Non-Match to Sample Task (DNMS). On each trial, participants compared a target object with a previously shown comparison object (Elliot & Dolan, 1999; see Figure 4.1b). In the non-match version of the task, participants are first shown an array of objects randomly displayed on a screen and, after a delay, the array is shown again, and they have to identify the object that has changed from the set of objects previously shown. In our case, we presented a set of seven faces from the Max Planck Face Database (Ebner et al., 2010), presented in a random position on the screen. The faces varied in age and gender to limit the influence of idiosyncratic features of each stimulus (15 females and 15 males for each of the three age groups). Depending on the condition to which participants were assigned, the faces displayed either neutral, fearful or angry expressions. The emotions expressed varied between participants. The first exposure to the face array lasted 2000 ms, followed by a fixation cross for 1500 ms, and then an array of seven faces appeared on the screen in the same position for 2000 ms, and participants had to identify the different face from the same array presented previously (i.e. six random faces were the same as on the first screen). In total, the task consisted of 42 consecutive trials, including a training period of 7 trials. Participants were instructed to right-click only on one of the faces, as clicking on the background screen of the trial was considered a 'no response'.

4.2.1.4 Procedure

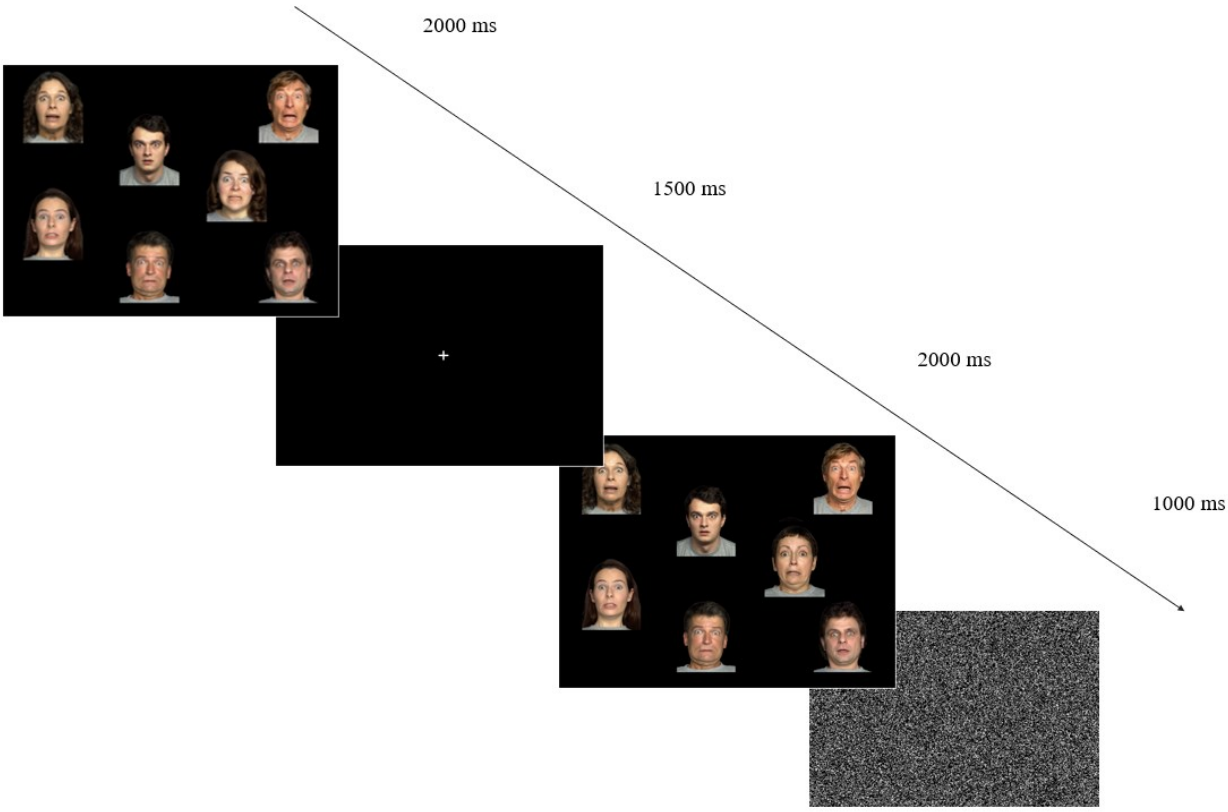
Participants were welcomed to an online experiment. They first completed the CBT, which continued for the maximum number of trials if they did not fail two consecutive times. Then, participants were invited to complete the DNSM with the emotional faces (neutral vs. fear vs. anger), which varied between subjects. They first completed 7 practice trials with different faces, and then the actual experiment began. Finally, they repeated the CBT, using the same rules as the first time. Then, demographic data (e.g. age, gender) were collected and participants were paid for their participation.

Figure 4.1. a) Examples of Forwards and Backwards Corsi Tapping Task (CBT, Corsi, 1971; Borchert, 2023). Retrieved from www.millisecond.com/download/librarycorsiblocktappingtas b) The "Revisited" Delayed Non-Match to Sample task (Elliot & Dolan, 1999), (i.e., with fearful emotional faces) extracted from The Max Plank database (FACES Ebner, Riediger & Lindenberger, 2010).The examples are reproduced with permission by the authors.

a)



b)



4.2.1.1 Data Preparation and Statistical Analyses

We conducted our analyses in R Studio. Our dependent variables were the CBT scores at T1 and T2 (total block span, as proposed by Kessel's et al., 2000, 2008) and the DNMS (scores and reaction times, RT). For each dependent variable, we checked the distributions of the variables and whether the assumptions of the tests were violated. When parametric tests were not applicable because the data did not meet the assumptions (i.e. normality of the residuals, homogeneity of variance), we either 1) identified the outliers likely to be behind the problems and removed them, or, if ineffective, 2) opted for more robust analytical techniques to overcome the assumption violation problem (more details in the following paragraphs). We report the analysis on the violation of assumptions of parametric tests and the descriptive analyses of our variables without outlier removal in Appendix 7.

The total block range of the CBTs was characterised by a few outliers that significantly affected the distribution at both times (T1 vs. T2). We used the interquartile range (IQR) method to identify the outliers and excluded 22 participants (final N = 302). After exclusion, the distribution of the data improved, and the assumptions of normality of the residuals and homogeneity of variance were not extremely violated. Therefore, parametric ANOVA was used to analyse these data.

The IQR method was again used to identify outliers in the RT of the DNMS, which was heavily influenced by a few observations, and we therefore excluded 16 participants (final N = 308) to optimise the data distributions. The respect for the assumptions of normality of residuals and homogeneity of variance improved, so we analysed the data with a parametric ANOVA.

We also tried to improve the severity of the right skewness of the DNMS scores, as most of the participants scored very high, but outlier removal using the IQR method was not effective. Data transformation was impractical as it lost the interpretability of the scores. Therefore, we decided to use a robust ANOVA, which allows the testing of interaction effects compared to other non-parametric techniques (Aligned Rank-based Transformation, with the "ARTtools" package for R, Kay et al., 2021).

We first tested our hypothesis that exposure to negative emotions could influence VSWM performance in a CBT according to the gender of the participants. Therefore, we ran a 2 (gender: female vs. male) x 2 (CBT Time: T1 vs. T2) x 3 (DNMS emotional condition: neutral vs. fear vs. anger) mixed ANOVA. In inspecting the interaction between the three factors, we calculated a differential score (T1-T2) for sake of simplicity. The higher the differential score was, the worse the performance at T2 compared to T1. Then, we explored the differences in the DNMS, as a way of quantifying the cognitive load imposed by concurrently processing facial negative emotions while performing a spatial memory task, always according to the gender of the participants. Thus, we ran a 2 (gender: female vs. male) x 3 (emotional condition: neutral vs. fear vs. anger) ANOVA for DNMS RT and DNMS scores, respectively. To inspect the association between DNMS scores and DNMS RT and CBT-T2 (while controlling for CBT-T1 as a covariate), we performed partial Spearman correlations for all participants, and then for each emotion and gender combination (as we found differences in the CBT performance due to gender, see results). We chose the Sperman correlations because it is more robust to outliers and abnormal distributions than Peason correlations.

Eventually, we conducted exploratory mediation analyses on the possibility that the differences found in the CBT after the emotional conditions were related to the cognitive load imposed by doing the DNMS when concurrently exposed to the emotional expressions (measured with the obtained scores). As CBT performance was influenced by gender differences, but DNMS performance was not (see results below), we analysed males and females separately. We included the differences between fear and anger or fear and neutral or anger and neutral as a predictor. We included DNMS scores as a mediator and CBT scores (T1-T2) as the dependent variable. Given the modest number of outliers identified and the fact that the use of classical mediation models was not possible without violating critical assumptions or losing several observations by removing outliers from an already limited sample size, we opted to run mediation models robust to such violations ("robmed" package, Alfons et al., 2022). Coefficients and indirect effects were tested by bootstrapping (Bca type, 5000 replicates).

In all cases, we reported statistical parameters and effect sizes (when available), and we analysed significant effects/interactions of ANOVA models with simple effects analyses (multiple comparisons were adjusted by the "Holm" method). All data and analysis scripts are available at https://osf.io/7u8vx/ .

4.2.2 Results

4.2.1.1 Analysis of Corsi Block Tapping Task (CBT) Performances

We ran a 2x2x3 mixed ANOVA with the total span as dependent variable (see Table 4.1 for the descriptives). Among the main effects, only the effect of time was significant $F(1,296) = 7.04$, $p = .008$, $\eta_p^2 = .03$, meaning that the performance improved after the second interaction compared to the first one. Then, there was a significant three-way interaction between emotions, gender, and time, $F(2,296) = 3.49$, $p = .03$, $\eta_p^2 = .02$. A simple effect analysis for inspecting this interaction showed that at T1 there was no difference for male, $t(562) < |1.88|$, $p > .17$, $d < .16$, and female participants, $t(562) < .81|$, $p > .99$, $d < .07$, before the exposure to the emotional conditions. Importantly, at time 2 we observed a significant difference in males after the exposure to fear when compared to neutral, $t(562) = -2.42$, p = .05, d = .20, such that the span is significantly smaller after the exposure to fear than neutral faces. No other comparisons were significant at T2 for males, $t(562) < |1.31|$, $p > .38$, $d < .11$, and females, $t(562) < |.46|$, $p > .99$, $d < .07$. When looking at the differences between T1 and T2 within each factorial combination, we found that, for females, performances improved significantly only after the fear manipulation, $t(296) = -2.28$, $p = .02$, $d = .13$, but not after the anger, $t(296) = -1.25$, $p = .21$, $d = .07$, and the neutral ones, $t(296) = -1.04$, $p = .30$, $d = .06$. (See Figure 4.2 a).

For males, performances improved after the anger manipulation, $t(296) = -1.94$, $p = .05$, $d = .13$, and the neutral condition (although not significantly), $t(296) = -1.83$, $p = .07$, $d = .11$. Importantly, the only condition in which the performance was more negative at T2 than T1 regards males after being exposed to fear, although the difference was not significant, $t(296) = 1.70$, $p = .09$, $d = .10$. The difference in the result pattern between males and female is emphasised also when computing a differential score (T2 – T1) for comparing the three emotion conditions. First, this analysis showed that in males the performance was significantly reduced after being exposed to fear than anger, $t(296) = 2.57$, $p = .03$, $d = .15$, or neutral conditions, $t(296) = 2.50$, $p = .03$, $d = .15$, but the difference was not significant between anger and neutral, $t(296) = .05$, $p = .96$, $d = .002$.

For females, the three conditions did not differ, $t(296) < |.76|$, $p > .99$, $d < .04$. Moreover, and importantly, we see that males were negatively and significantly more affected than females after the fear condition, $t(296) = -2.80$, $p = .005$, $d = 16$, but the difference was not significant after the anger, $t(296) = .41$, $p = .68$, $d = 02$, or neutral ones, $t(296) = .49$, $p = .63$, $d = 03$. No other effects were significant, $F < 1.14$, $p > .28$, $\eta_p^2 < .004$. (See Figure 4.2 b).

4.2.1.2 Analysis of Delayed Nonmatch to Sample Task: Reaction Time Performances

The analysis on the 2 (gender) x 3 (emotions) ANOVA yielded no significant differences (see Table 4.2 for descriptives), gender: $F(1,302) = 1.93$, $p = .16$, $\eta_p^2 = .006$, emotions: $F(2,302) = 1.97$, $p = .14$, $\eta_p^2 = .01$, interaction: $F(2,302) = .43$, $p = .64$, $\eta_p^2 = .002$. (See Figure 4.3 a)

4.2.1.3 Analysis of Delayed Nonmatch to Sample Task: Score Performances

The 2 (gender) x 3 (emotions) robust ANOVA (see Table 4.2 for descriptives) resulted in a non-significant effect of gender, $F(1,318) = 1.32$, $p = .25$, $\eta_p^2 = .004$, but a significant effect of emotions, $F(1,318) = 7.32$, $p < .001$, $\eta_p^2 = .04$. When comparing the three conditions, participants' performance in the fear condition was worse than that in the anger condition, $t(318) = -3.81$, $p < .001$, but not different from the neutral condition, $t(318) = 1.51$, $p = .13$. Participants in the anger condition performed slightly better than in the neutral condition but not significantly, $t(318) = -2.17$, $p = .06$. (Figure 4.3 b).

4.2.1.4 Correlations between DNMS (Scores and RT) and CBT

The partial correlations including all participants (N = 324) found a significant and positive correlation between DNMS and performances in the CBT at T2, Spearman $\rho = .12$, $p = .03$, and a negative association with RT, $\rho = -.14$, $p = .01$, which suggests that participants with high DNMS scores and faster DNMS reaction times had a positive performance in CBT. Then, we inspected the correlations according to the combinations of gender and emotion conditions. For males in the fearful faces condition (n = 58), there was a marginal but non-significant positive association between DNMS scores and CBT, $\rho = .25$, $p = .06$, meaning that participants performing bad in the DNMS were bad as well in the CBT, but no association with the RT, $\rho = -.17$, $p = .18$. For females in the fearful condition (n = 57), there was a negative association with the RT, $\rho = -.38$, $p = .003$, meaning that participants that were fast in the DNMS were also those performing well in the CBT, but no association with the scores, $\rho = .19$, $p = .14$. For males in the angry condition (n = 59) and in the neutral condition (n = 54), there were no association at all, $\rho > -.15$, $p > .24$, and $\rho < .13$, $p > .35$, respectively, as well as for females in the angry (n = 51) or neutral conditions (n = 45), $\rho > .05$, $p > .24$, and $\rho > .04$, $p > .74$, respectively.

4.2.1.5 Exploratory Mediation Models

The above analyses revealed potentially relevant differences in emotional conditions (depending on gender). In DNMS, performance was negative when participants were exposed to fearful expressions rather than to the other emotions. In CBT, performance was negative after exposure to fearful faces (vs. others), but only for males. Furthermore, there was a positive relationship between DNMS and CBT scores for males, but not for other emotions. One might wonder whether the score of the DNMS could predict the score of the CBT depending on the emotional conditions. More specifically, this analysis aimed to investigate whether the negative performance observed in the DNMS during the fearful condition, which could be interpreted as a higher cognitive load imposed by the elaboration of fearful faces compared to other emotional faces, can explain the subsequent negative performance in the CBT. To explore this, mediation models were fitted with DNMS scores as mediators. Differences between emotional conditions (fear vs. anger, or fear vs. neutral, or anger vs. neutral) were used as predictors of CBT performance (T1-T2) and DNMS scores.

We examined male and female participants independently. We did not calculate models including DNMS RT because the ANOVA did not show a significant difference of either gender or emotion. Results are reported in Figure 4.4 and 4.5.

We did not find significant indirect effects in any of the mediation models. However, in males, we could identify a nonsignificant pattern in the indirect effect of the comparison between fear and anger conditions, such that those who performed worse while exposed to fearful (vs. angry) expressions in the DNMS tent to also to perform worse in the CBT.

Figure 4.2 Line and violin plots representing the difference in performance in total block span between CBT (Time 1) and CBT (Time 2) sessions and differential score (T1-T) as a function of gender and emotional conditions. Higher numbers indicate better performances in graph a, and lower numbers indicate better performances in graph b. The light blue line represents female participants, and the orange line represents male participants. Bars represent standard error around the means.

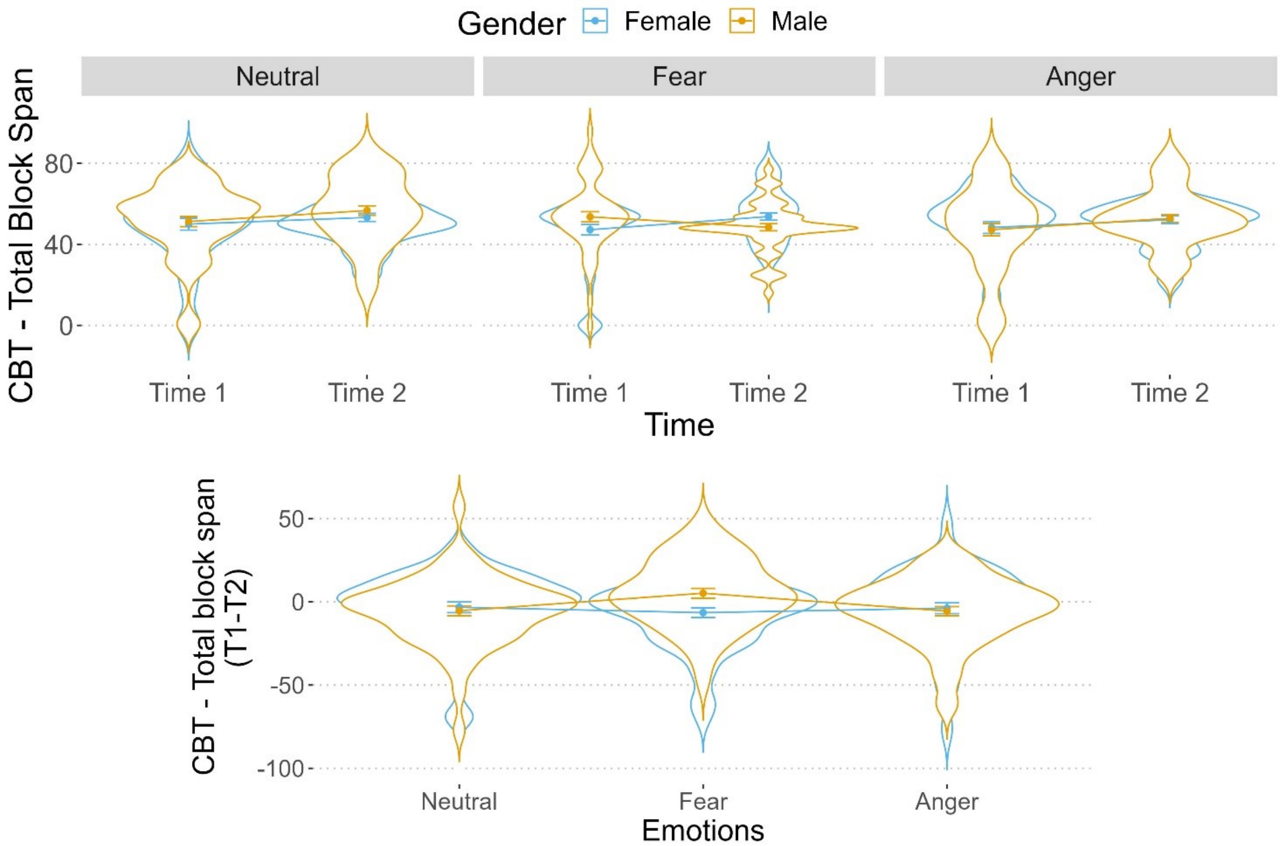
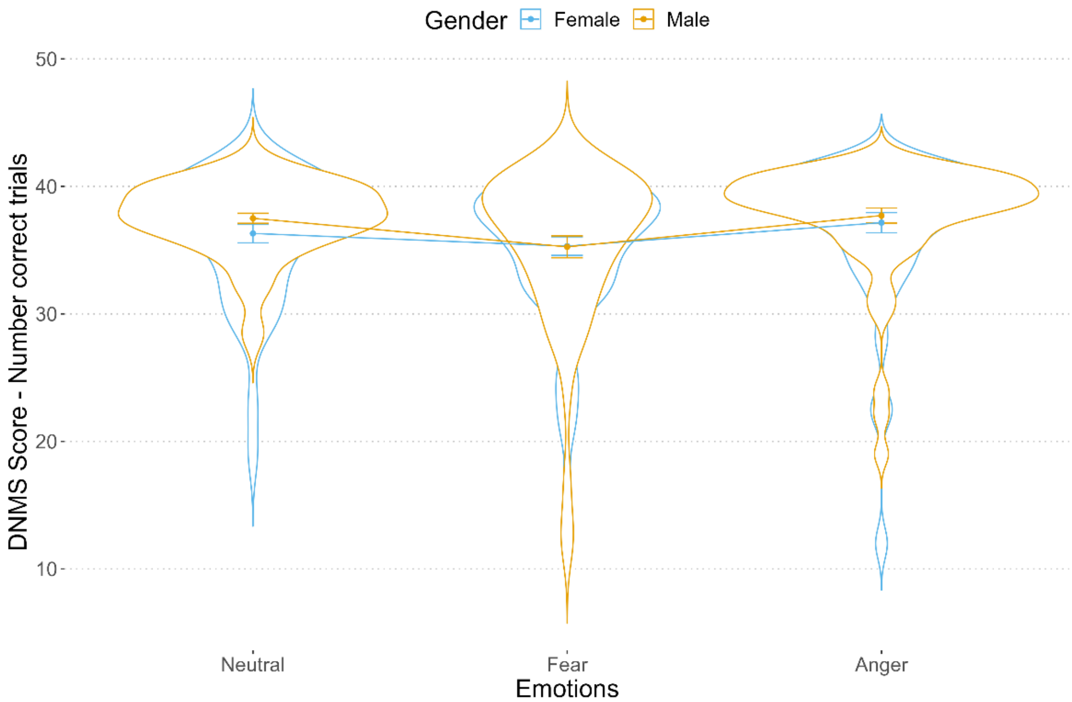


Figure 4.3 Line and violin plots representing the difference between DNMS score (a) and DNMS reaction times (b) as a function of gender and emotional conditions. Higher numbers indicate better scores in graph a, and higher numbers indicate slower times in graph b. The light blue line represents female participants, and the orange line represents male participants. Bars represent standard error around the means.

a)



b)

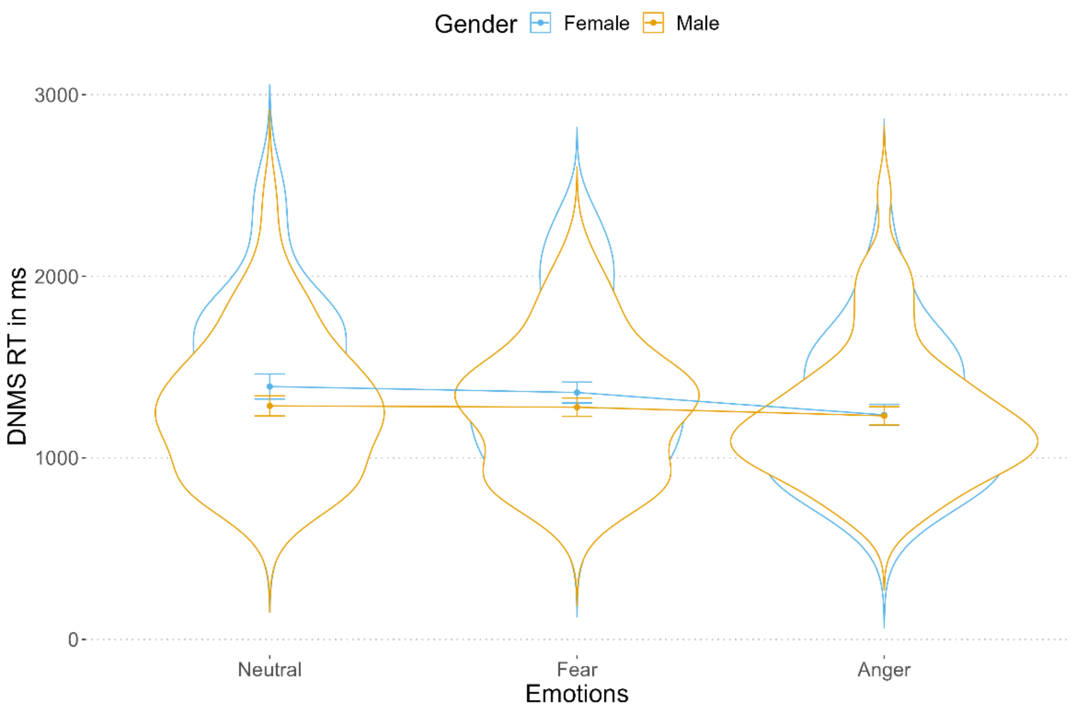


Table 4.1 Means and standard deviations (in parenthesis) and median and interquartile range (in parenthesis) of Corsi Block Task (CBT) expressed in percentages of success at T1 and T2 as a function of gender and emotional condition. Outliers were removed.

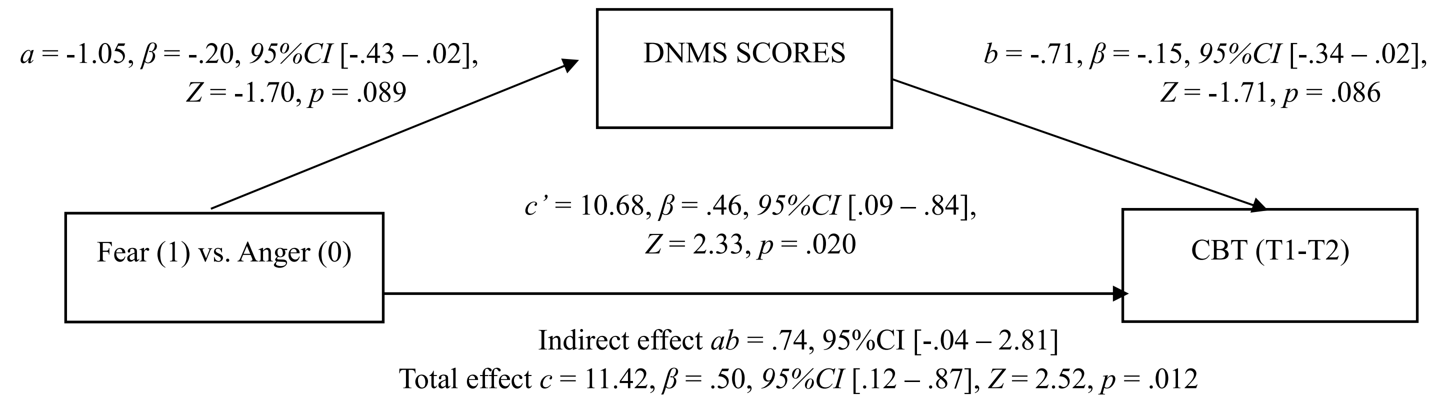
	Females					
Emotions	Neutral		Fear		Anger	
Tasks	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
CBT - T1	50 (19.8)	54 (18)	47.2 (19.3)	54 (10.5)	48.3 (20.2)	54 (19)
CBT - T2	53.3 (13.4)	54 (12)	53.7 (13.4)	54 (15)	52.2 (13.6)	54 (12)
	Males					
Emotions	Neutral		Fear		Anger	
Tasks	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
CBT - T1	51.3 (18.3)	54 (15)	53.6 (17.7)	54 (12)	47.2 (22.3)	49.5 (20)
CBT - T2	56.7 (16.8)	57 (22.8)	48.4 (12.2)	48 (6)	52.8 (14.2)	54 (14.2)

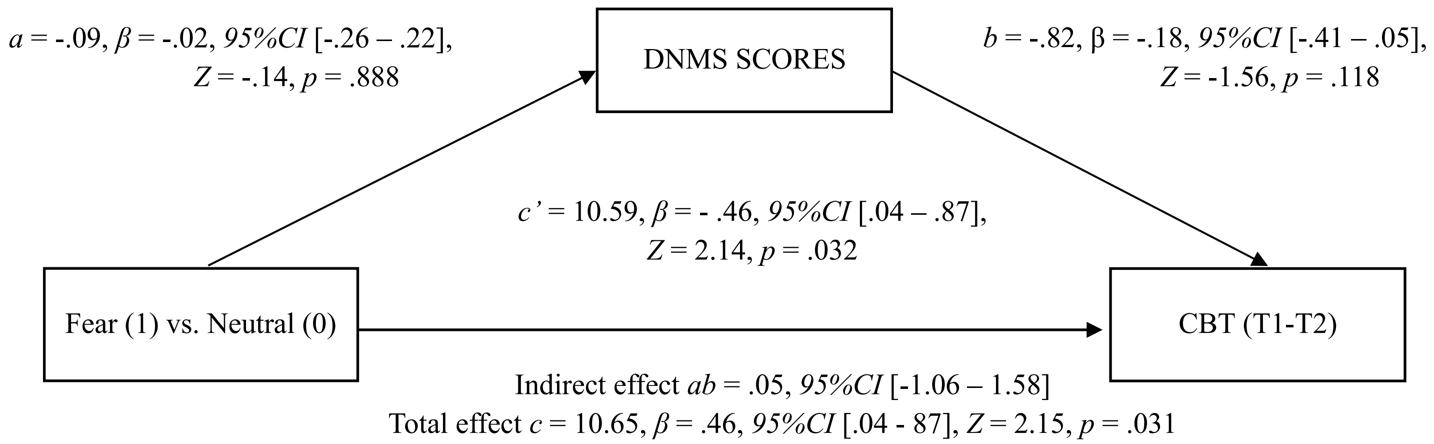
Table 4.2 Means and standard deviations (in parenthesis) and median and interquartile range (in parenthesis) of the Delayed Non-match to Sample task (DNMS) expressed in scores and reaction times as a function of gender and emotional condition. Outliers were removed in DNMS RT but not in DNMS Scores. In the latter we used all participants and a more robust analysis because removing them did not change the situation.

	Females					
Emotions	Neutral		Fear		Anger	
Tasks	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
DNMS-SC	36.3 (4.93)	38.0 (6.00)	35.3 (5.51)	37.0 (6.00)	37.2 (5.62)	39.0 (4.00)
DNMS-RT	1393 (449)	1288 (652)	1360 (432)	1323 (512)	1237 (406)	1134 (550)
	Males					
Emotions	Neutral		Fear		Anger	
Tasks	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
DNMS-SC	37.5 (2.89)	38.0 (3.75)	35.3 (6.52)	37.0 (7.00)	37.7 (4.57)	39.0 (3.00)
DNMS-RT	1286 (393)	1252 (578)	1279 (368)	1290 (535)	1231 (378)	1165 (419)

Figure 4.4 Robust mediation models: males. We performed simple mediation models, separately for each gender, with DNMS scores (not RT) as mediator for explaining the emotional conditions differences in the CBT (T1-T2). The higher the differential, the worse the performance at T2 compared to T1. We reported the bootstrapped effects, the standardized coefficients along their confidence intervals (95%CI), and the Z tests with the *p*-values when available. Indirect effects are based on unstandardized coefficients.

MALES





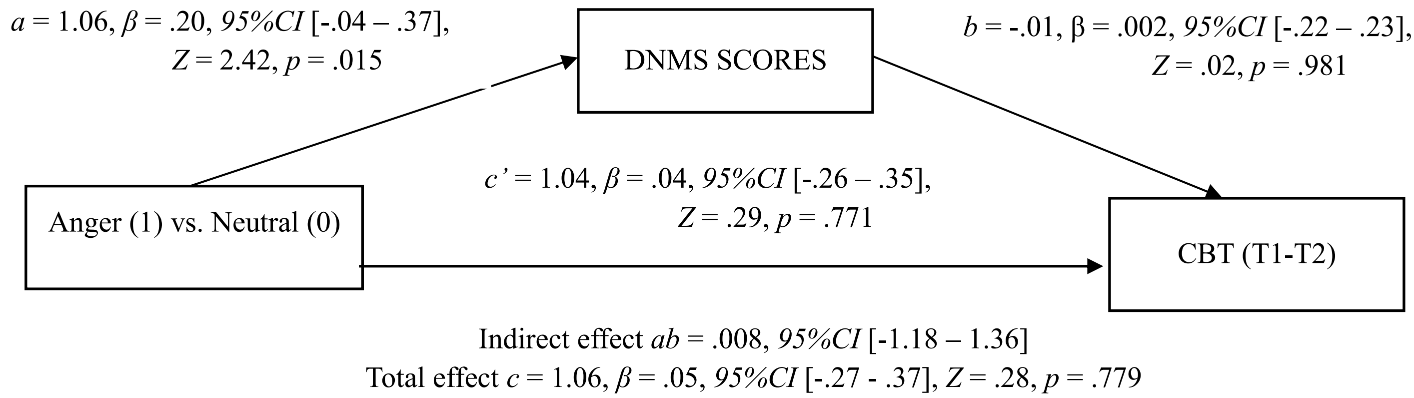
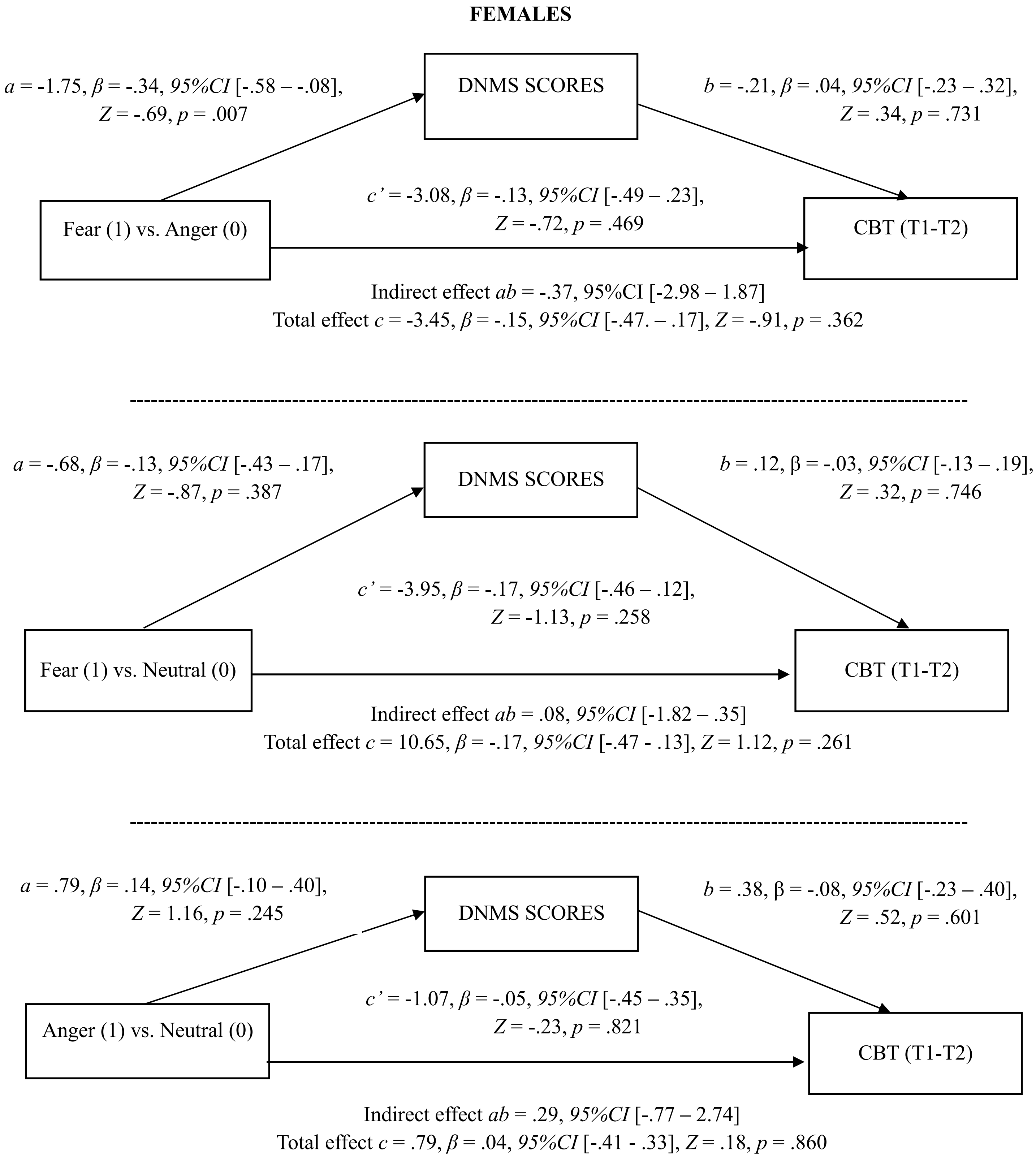


Figure 4.5 Robust mediation models: females. We performed simple mediation models, separately for each gender, with DNMS task scores (not RT) as mediator for explaining the emotional conditions differences in the CBT task (T1-T2). The higher the differential, the worse the performance at T2 compared to T1. We reported the bootstrapped effects, the standardized coefficients (β) along their confidence intervals (95% CI), and the Z tests with the *p*-values when available. Indirect effects are based on unstandardized coefficients.



4.2.3 Discussion

Previous research has tested the influence of facial emotion on VSWM when presented in the same task. However, little is known about the influence of processing facial emotion for a subsequent task involving VSWM. Hence, we asked participants to complete a Backward Corsi Block Tapping Task (CBT) to assess their baseline VSWM abilities. They then completed a Delayed Non-Match to Sample Task (DNMS) in which neutral, fearful or angry faces were used as target objects. Finally, we assessed whether the latter task affected VSWM abilities depending on the emotion displayed. For this reason, they were asked to repeat the CBT once more. Overall, the study aimed to contribute to the understanding of how emotional stimuli affect VSWM and CBT performance, taking into account potential gender differences in these cognitive processes. In line with previous research (Gambarota & Sessa, 2019), faces in the DNMS were task irrelevant.

We hypothesised that negative face stimuli should impair VSWM more than neutral stimuli (Hp1). Furthermore, fearful faces may have a stronger effect on VSWM load (Curby et al., 2019; Gambarota & Sessa, 2019), leading to the hypothesis of a stronger effect on DNMS scores and times (Hp2) and subsequent CBT performance (Hp3). Regarding gender differences, previous research suggested a potential male advantage in VSWM, albeit small (Coluccia & Louse, 2004; Voyer et al., 2017).We expected males to outperform females on the first VSWM task (CBT-T1 or before emotional exposure; Hp4). However, females are often better at identifying, recognising, and regulating emotions (Hoffman et al., 2010; Kret & de Gelder, 2012; Saylik et al., 2018) and may therefore show less detrimental effects than males (Hp5). Finally, we hypothesised that DNMS performance should correlate with CBT performance due to the load imposed on the DNMS and transferred to the CBT, and this should be true when fearful faces were presented in the DNMS (Hp6). Finally, to explore the existence of a relationship between our DNMS manipulation and the improvement or deterioration of VSWM abilities, we examined indirect effects in mediational models that might explain differences between emotions, DNMS, and CBT.

We found that participants were significantly affected by negative expressions in both the DNMS and the subsequent CBT (consistent with Hp1, Hp2 and Hp3). First, DNMS performance was reduced when faces were fearful rather than angry or neutral (consistent with Hp2), but no gender differences were observed in the DNMS (not consistent with Hp5). Furthermore, we did not observe a male advantage on any of the tasks (not consistent with Hp4). Second, performance on CBT-T2 (vs. CBT-T1) decreased only after the fearful condition (consistent with Hp3). However, this latter result was moderated by gender differences, as it was observed only in males and not in females (consistent with Hp5). Third, we examined the relationship between DNMS and CBT performance in a series of correlations. We found that, for males in the fearful condition, DNMS scores (not RT) and CBT scores were positively associated, but not significantly (not consistent with Hp6). Finally, exploratory mediation models found informative but non-significant evidence that males' poorer CBT-T2 performance after fearful faces could be explained by their mediocre performance on the DNMS with fearful (compared to angry faces). These results need to be confirmed in future research.

Fearful, but not angry or neutral, faces reduced DNMS performance is consistent with previous findings using similar tasks (e.g., Curby et al., 2019). However, we used a DNMS in which the spatial component of the task was more emphasised than in Curby et al.'s study, because in the second phase of the task we presented the face array with six original faces and one novel face, forcing participants to search for a new identity (i.e., incongruent one) and locate it on the screen. Faces positions changed from trial to trial, potentially requiring more VSWM resources than prior studies.

Our task may provide stronger evidence that processing threatening stimuli can impair both the visual and spatial components of VSWM. In turn, this finding suggests that fearful faces may engage working memory and attention differently than angry faces. For example, given that angry faces are better remembered than fearful faces (Davis et al., 2011), this could mean that performing a DNMS may have been easier for angry faces than for fearful faces. Alternatively, given that fearful faces can be more salient than angry faces in a task-irrelevant presentation (Engen et al., 2017), and that we presented seven faces at once, this could have increased competition between stimuli in working memory and thus disrupted performance (see Curby et al., 2019 for a similar reason). However, it is important to note that a) performance was always very high in all three conditions, and b) there was no difference in reaction times. Both may be explained by the fact that, unlike previous research (Gambarota & Sessa, 2019), we did not include a reaction time constraint. This is a factor known to increase load and decrease performance (Barrouillet et al., 2007), and could reduce or increase differences between emotion conditions (e.g., Curby et al., 2019). Thus, emotion-specific differences could also be modulated by the inclusion of a time limit in a measure such as ours, an issue that should be explored in future research.

We also found emotion-specific differences in the CBT, such that performing a VSWM task with fearful faces impaired performance on a subsequent task more than when it included angry or neutral faces, although this difference was only observed for male participants. We hypothesised that emotional faces might influence the available resources of VSWM, and therefore that exposure to and processing of emotions in a VSWM might influence performance on a subsequent VSWM task (Schmeichel, 2007; Sweller et al., 1998, 2011). Indeed, fear was able to influence both VSWM tasks in a similar way (except for the gender moderation), suggesting a possible relationship between the two negative outcomes. This relationship was highlighted by the positive correlation between DNMS and CBT scores for males, but not for females. However, it was marginal and not significant. Similarly, the descriptive pattern of the mediation model suggests that there may indeed be a relationship between performance on the two tasks due to the high cognitive load imposed by fearful (vs. angry) faces in the DNMS (and the lack of significance could be due to several factors, one of which is the potentially low statistical power to test a mediation hypothesis, which could be related to the small sample size). Therefore, we could suggest that the cognitive load hypothesis is still valid, but these results are preliminary and require further investigation to assess it.

This is one of the first studies on the cognitive load hypothesis on VSWM using emotions and has provided a direction for new studies. These should use different VSWM tasks to ours to increase the validity of the tests of our hypothesis. The cognitive load hypothesis may not be the only explanation for this 'transfer' effect of negative performance. Differences in working memory capacity have been found to be related to emotion regulation, which may play a role in this experiment (Schmeichel et al., 2008; Garrison & Schmeichel, 2019), as exposure to negative stimuli may increase anxiety or negative feelings through emotion contagion (Elfenbein et al., 2014; Hatfield et al., 2014). WM capacity is also related to the influence of cognitive load on cognitive tasks and self-control, as lower capacity increases load and decreases control (Chen et al., 2018; Hofmann et al., 2008). WM resources may be particularly relevant as emotion regulation strategies may differ between genders (Goubet & Chrysikou, 2019), and the selective use of different regulation techniques may also explain gender differences. Given the relationship between WM capacity and such variables, future research could include it as a moderator to assess whether individuals with high working memory capacity are more resilient to the detrimental effects of negative emotion processing than those with low capacity.

Interestingly, we did not find gender differences in the CBT or DNMS tasks regardless of the emotion manipulation, which challenges the idea that males might be better than females at VSWM tasks (Coluccia & Louse, 2004; Voyer et al., 2017; cf. Robert & Savoie, 2006). However, when looking at the influence of emotions, we found interesting results. In the DNMS there were no gender differences in the emotional conditions, suggesting that when a threatening emotion is presented contingently to a VSWM task its detrimental effect is powerful enough to impair both genders performances. However, we found that males and females were differentially affected by emotions in the second CBT, that is after the repetitive exposure to emotions. This finding could be interpreted as evidence that males may be more sensitive than females to threatening emotional expressions, particularly fear, when it comes to recover from the emotional exposure (Kret & de Gelder, 2012; Han et al., 2018; Saylik et al., 2018). Although we did not find striking evidence of a direct relationship between CBT and DNMS scores, we did not rule out the possibility that the effect could be due to a greater depletion of cognitive resources in males compared to females, which could be measured in other ways (e.g., measuring the attention devoted to fearful faces during the DNMS, Engen et al., 2017, Davis et al., 2011), or that females may be better able to control the transferred effect of emotion processing on their second performance (i.e., better emotion regulation). These latter results are also consistent with the findings in our previous chapters, where spatial navigation behaviour and (some) spatial tasks were impaired by processing fearful (rather than angry or neutral) faces, both situations in which VSWM should be strongly implicated. Also, these results significantly extend the findings reported in the previous chapters by revealing relevant differences at a fairly basic cognitive level.

The present study is not without limitations. In particular, we used two tasks that may relate differently to VSWM: the CBT may measure spatial working memory more accurately, whereas the DNMS the visual working memory. Although the two components are related, they can also be dissociated (Baddeley, 2007; Baddeley & Logie, 1999). Researchers might consider including different types of tasks that target one type of working memory to test whether our results apply to one or the other. Second, we only used negative emotions, but previous research on VWM has also found effects due to positive facial expressions (Gonzales-Garrido et al., 2013). It is plausible that similar effects to the ones we found should also extend to this type of emotion. Finally, we did not include behavioural measures that could reveal important patterns of attention to faces (i.e., eye tracking), an addition that future research should consider for understanding how attention might be diverted or captured by diverse types of emotional stimuli in these tasks. Overall, the findings reported in this chapter shed light on the effect played by negative emotional expressions, in particular fearful faces on both VSWM and spatial navigation. This last experiment provided an answer to our last open issue, completing the findings of the previous Chapters.

GENERAL DISCUSSION

5.1 Summary of the Aims and of the Main Findings

The aim of the present dissertation was to investigate how negative emotional information affects spatial navigation and related skills. Previous research has explained the factors that contribute to spatial navigation and visuospatial skills (Burgess, 2008; Wolber, 2015; Epstein, 2017; Ekstrom et al., 2018; Pessoa, 2012; Zhao et al., 2024; Ruotolo et al., 2018). However, the influence of negative emotion processing on these mechanisms is still not well understood. Individuals encounter various stimuli in daily life. Some stimuli have high social value, such as the emotional states of others expressed through their faces (Ekman, 1993). We investigated whether emotional expressions of unfamiliar individuals processed while performing spatial tasks influence their performance. We specifically examined whether facial emotional expressions enhance or inhibit participants' wayfinding, spatial navigation cognitive tasks, and visuospatial skills.

We first studied the impact of emotional expressions on wayfinding behaviour. Initially, we examined the effect of emotional facial expressions. Later, we expanded our research to investigate whether emotional bodies or contextual scenes could also affect wayfinding. The second topic we examined was the potential distinctions between fearful and angry expressions. The literature suggests that there may be similarities and differences in the effects of these emotions on cognition and behaviour (Adams et al., 2006; Mirabella, 2023; Paulus & Wentura, 2016; Seidel, 2010). However, to our knowledge, no study has directly compared their effects on wayfinding and spatial tasks. Our third open question pertained to gender differences. Acknowledging the prominent gender differences in spatial abilities and social cognition (Lowe et al., 2003; Saylik et al., 2018), we proposed that these differences may affect the interplay between spatial navigation and facial emotion processing. We considered whether the processing of fearful or angry facial expressions affects spatial navigation domains (van der Ham et al., 2020), extending our initial findings on wayfinding behaviour. Finally, the fifth issue examined the role of emotional faces in modulating visuospatial working memory performance, a very basic cognitive function required for effective navigation.

In Chapter 2 we provided an initial response to the first three open questions by using faces, bodies, and contextual scenes as stimuli to determine their impact on wayfinding in a realistic virtual environment. Experiment 1 examined participants' wayfinding behaviour before and after exposure to emotional faces. Participants were required to explore an environment to reach a target object during the encoding phase. In the recall phase, they had to navigate the same environment to the same target object. Additionally, they had to categorise a set of faces expressing fear or anger or bearing a neutral expression. We hypothesised an effect of negative emotion processing and examined whether it was emotion-specific and took gender differences into account. On average, males performed better than females in spatial navigation tasks, which is consistent with what has been established and reported in literature. The effect of negative emotions on navigation was evident, with a significant interaction with gender. Fearful faces disrupted navigation in males, but had no effect on females, while angry and neutral faces showed no effect. In Experiment 2, we aimed to determine whether navigation performance was influenced by fearful, angry, or neutral bodies (with blurred faces), similar to the effects of fearful faces observed in our previous experiment. The emotional bodies did not show any significant differences in their impact on navigation. In Experiment 3, we tested whether negative non-social stimuli, such as threatening contexts, can affect wayfinding performance as much as social stimuli, such as faces. Our study found no evidence to suggest that emotional contexts exerted an effect on wayfinding performance.

In Chapter 3 we aimed to assess the impact of negative facial expressions on navigation domains, such as landmark, location, and path knowledge (van der Ham et al., 2020). In Experiment 4, participants were asked to recall details while observing a video recording of an avatar person searching for an object navigating through the rooms of a building. This was followed by a gender categorisation task involving neutral, fearful, or angry faces. Six tasks (i.e., landmark recognition, landmark identification in context; route ordering; directional pointing; map recognition; object positioning on map) assessed participants' spatial abilities in different domains (i.e., landmark, location, path). Gender differences were observed in tasks involving allocentric location strategies and path survey knowledge, with males outperforming females in neutral conditions. However, the processing of fearful and angry faces had a negative impact on the advantage of male performance in the location task. This was due to a decrease in male performance and an increase in female performance. In the path survey task, only fear had a similar effect. No differences were observed in the other tasks in relation to emotion processing.

In Chapter 4, we expanded our research to include cognitive factors that could explain our previous findings. We also investigated how emotional face processing impacts visuospatial abilities. In Experiment 5, we tested whether processing emotional faces in a visuospatial working memory task would affect performance on another visuospatial working memory task. The emotional faces included neutral, fearful, and angry expressions. The first task was a delayed non-match to sample task (DNMS), while the second task was a backward Corsi block tapping task (CBT). We compared the results to the baseline performance of this latter task. Negative emotional stimuli were expected to have a greater impact on DNMS performance than neutral stimuli. Fearful faces, but not angry or neutral faces, reduced DNMS performance for all participants. The subsequent CBT task was affected only in males, consistent with previous findings in navigation, while females performed as well as at baseline. We examined the relationship between the decline in performance on the two tasks. We found a trend for a relationship between DNMS and CBT performance in males due to fear processing, although it was not significant. This might suggest that processing of emotional faces in the first task may underlie the decline in the latter, but not in females. It requires further investigation.

Overall, our results indicate that processing negative emotions, particularly fearful faces, can impact wayfinding behaviour, spatial navigation, and visuospatial abilities. In most cases, this has a negative effect on males only, while females are either unaffected or slightly enhanced in their performance.

5.2. Implications of the Results

This research has provided several lines of evidence that processing facial emotional expressions can affect visuospatial working memory, spatial navigation and its domains. To address the first open question, we conducted three experiments measuring behavioural responses in a realistic virtual reality environment. Our results indicate that facial emotions, especially fearful faces, affect wayfinding outcomes. Faces have a high communicative value (Sato & Yoshikawa, 2013). Recognising faces and their emotional expressions in spatial contexts provides an adaptive advantage. This helps to predict the future actions of others or what is happening in the environment and adjust behaviour accordingly (Davis et al., 2011; Gonzalez-Garrido et al., 2013). The first three experiments aimed to determine whether emotional stimuli have an effect on wayfinding behaviour. We specifically investigated whether the effects of emotional faces differed from those of other social (i.e., bodily emotional expressions) or non-social (i.e., emotional scenes) stimuli. Interestingly, we did not observe the same effects of faces in either emotional scenes or emotional bodies.

While the lack of effect with emotional scenes suggests that social stimuli may have a stronger influence on navigation than non-social stimuli (Dalton et al., 2019), the fact that the effect does not generalise to bodies may highlight a face-specific pattern of influence. Other people's facial expressions, compared to body and emotional scenes, may provide better and faster information about the events unfolding around an individual, ultimately determining a higher proportion of resources devoted to threat detection and optimal navigation. Thus, faces may be more influential than scenes or bodies because of their exceptional value and influence on our behavioural responses. Furthermore, a possible explanation could be based on the evolutionary behavioural responses elicited by faces (e.g. approach-avoidance or fight/flight; Adams et al., 2006; Kreibig et al., 2007; Stins et al., 2011). Faces can quickly and effectively signal potential danger and elicit adaptive behavioural responses such as increased vigilance or avoidance (Hatfield, Cacioppo, & Rapson, 1994; Hess & Bourgeois, 2010). In the context of navigation, the perception of emotional faces may be particularly relevant for survival, and humans may be evolutionarily predisposed to prioritise the processing of threatening information expressed by the face (Rotteveel et al., 2001) over that coming from bodies or scenes, presumably to prevent or cope more effectively with events surrounding the individual (Elfenbein, 2014; Hareli & Parkinson, 2008). Although our evidence suggests this, we did not compare the three types of stimuli in a single experiment due to its potential design complexity, which may provide a more powerful test of this idea. In addition, it is worth noting that Experiment 2 used emotional bodies and had a small and unbalanced sample size compared to Experiment 1 with faces or Experiment 3 with scenes. Due to time constraints, we were unable to recruit more participants. Looking at the descriptive statistics, it appears that fearful bodies were more effective than angry ones, similar to the pattern observed with faces. Future studies should increase the sample size to test whether this effect is specific to faces or can be generalised to other social stimuli like the human body.

With regard to our second open question, we found discrepancies in the effects of processing negative emotions, specifically fear and anger, on wayfinding. In Experiment 1, participants were presented with fearful and angry expressions prior to navigating again. Our results indicate that only fearful faces reduced (males') wayfinding performance. Based on the above argument, we propose that the processing of fear and anger triggers behavioural responses that affect wayfinding, albeit with different consequences. Fear is a response to danger that prepares individuals to assess and respond to potential threats. It triggers physiological arousal and increases attention to details in the environment. Exposure to fear can signal a source of threat that requires attention, such as a fire in the office. This effect is stronger than for anger (Davis et al., 2011). Fearful faces can continue to affect people's ability to navigate even after they are no longer visible. In contrast, anger is a more immediate threat directed at the observer in the present context. Angry faces can indicate interpersonal threats, such as aggressive intentions. Once the faces disappear, the perceived threat disappears and does not affect subsequent navigation. The nature of the threat, whether directed at the observer or emanating from an unknown source, may play a crucial role in shaping an individual's navigational responses. Exposure to emotion may also be a possible and related explanation, as suggested by contagion (Hatfield et al., 1994). People instinctively tend to match the emotional states they perceive during interactions with others (Kret, 2017; Schachter & Singer, 1962). Emotional contagion can alter an individual's emotional experience and cognitive and behavioural responses. For example, participants exposed to fearful faces may have begun to feel a similar state (i.e., fear or anxiety) themselves, and such feelings may have affected their wayfinding performance (Barsade, 2002; for a review, see Hatfield et al., 2014). Studies using induced threat have shown that increased anxiety is associated with a reduced tendency to explore the environment (Kallai et al., 2007; Newcombe, 2019). The repeated exposure to emotional faces in Experiment 1 may have induced anxiety after fear (but not anger). Further studies should examine the effects of emotional contagion on wayfinding.

To address the third issue, gender differences have been considered. Gender differences in spatial tasks and the influence of emotions on performance have been investigated also in navigation domain tasks (Experiment 4) and VSWM tasks (Experiment 5), providing crucial evidence in this area. Therefore, we will also discuss navigation domains and VSWM, as they are inextricably linked to the latter two topics and to our initial findings on gender differences in wayfinding. Research suggests that females generally perform worse than males on spatial navigation and VSWM tasks. This applies to both large-scale spatial skills, such as navigation and orientation, and small-scale spatial skills, such as visualisation and spatial relations. However, females may outperform males on landmark-based tasks. In Chapter 2, gender differences were found in almost all experiments, mostly in travel times, which measured wayfinding in virtual reality. In Experiment 4, there were differences in some of the most cognitively demanding spatial navigation tasks, such as path knowledge and location tasks, but not in landmark-based tasks, which is consistent with previous findings (van der Ham et al., 2020). However, no gender differences were found in Experiment 5, which assessed basic VSWM performance. Gender differences might become more pronounced with high cognitive load (Coluccia & Louse, 2004; van der Ham et al., 2020). Overall, our results seem to suggest that the differences have mostly been observed in complex tasks that require a higher visuospatial skill.

Furthermore, research suggests that females may have a greater aptitude for emotion processing (Olderbak et al., 2019), whereas males tend to show stronger responses to threat cues (Han, 2008; Kret & De Gelder, 2012). These gender differences in emotion processing may help to explain the results of Experiments 1, 4, and 5. Gender differences in emotional impact may be due to how they manage visuospatial working memory (VSWM) resources when elaborating emotional faces during visuospatial tasks (Baddeley et al., 2012; Brown & Chrastil, 2019). VSWM resources are used for different tasks, including navigation and simpler cognitive tasks (Aagten-Murphy & Bays, 2019; Labate et al., 2014; Wen et al., 2011). The same cognitive resources used for navigation and cognitive tasks may also be required to process negative emotions from faces. Studies have shown that the brain regions (i.e., left dorsolateral and right ventrolateral prefrontal cortices; bilateral intra-parietal sulcus; supramarginal gyrus in posterior parietal cortex) responsible for processing object identity, spatial localisation, and retrieval of visuospatial representations, known as VSWM, is also involved in encoding and storing fearful and angry facial stimuli (Brown & Chrastil, 2019; Maratos et al., 2020). Indeed, VSWM performance can be affected by the processing of emotional stimuli, in particular fearful faces (Curby et al., 2019; Davis et al., 2011; Pessoa, 2008).

Therefore, we proposed that emotional faces, particularly fear, have a greater impact on VSWM and that females are better than males at managing VSWM resources for emotional face processing (Olderbak et al., 2019). With this in mind, we will examine the results of Experiment 5, which directly addressed this issue. Males' performance on a VSWM task (CBT) decreased after exposure to fearful faces in a previous task, whereas females' performance remained unaffected. This may support the idea that gender differences in VSWM account for the results observed in the previous experiments. Moreover, both males and females showed similar declines in performance when processing fearful faces presented simultaneously with the DNMS task. Importantly, we found that for males the decline in the subsequent task (i.e., CBT) was descriptively associated with decline in the previous task (i.e., DNMS) when fearful faces were shown.

This finding is significant because it suggests that while males may not have fully recovered from using VSWM resources to process fearful faces, females may be better able to recover from the effects of fear processing. In other words, females may be better equipped to cope with the cognitive load of processing emotional faces and therefore be less depleted for the subsequent task (Schmeichel et al., 2008). It is possible that females are better at managing emotionally charged tasks than males because they use emotion regulation strategies more effectively (Goubet & Chrysikou, 2019; Nilsonne et al., 2021). This could be a possible explanation for the results of Experiments 1 and 4. Females may have counteracted the influence of face emotion processing over time, which could help them to control its influence on the subsequent task. However, the evidence is not strong and future research should consider what factors might favour the suggested pattern to emerge. For instance, one possibility may be considering the relationship between emotion regulation strategies and spatial navigation and visuospatial abilities, particularly in the context of gender differences. This aspect was not investigated in the present study. Overall, our results provide first indirect evidence for a link between emotion processing and navigation through VSWM and address our open questions.

5.3 Limits and Further Investigation

Although our study provides valuable insights, it is important to consider its limitations. Limitations relate to practical and methodological choices. For example, the virtual reality environment used in Chapter 2 was limited to a small-scale closed environment (i.e., office building), which may affect the generalisability of the findings to larger outdoor environments where navigational strategies may differ (Ekstrom & Isham, 2017). To increase ecological validity, future research should expand its scope to include different environmental contexts.

Furthermore, it is important to acknowledge the limitations associated with sample size. Despite collecting data from over 130 participants in the VR environment, which requires extensive work and time, Experiment 2 was significantly limited compared to the others. We could not reach our target sample size due to time constraints imposed by the present dissertation. The limited number of observations on which the analyses were performed and the unbalance of gender (i.e. females were twice than males) may explain the lack of significant findings, despite a trend in line with expectations. In Chapters 3 and 4, larger sample sizes were collected based on a priori power analyses, overcoming the limitations of previous studies. Importantly, some of the findings in these latter, more powerful studies were conceptually consistent with Experiment 1, suggesting a common ground. Future work should take this limit into account.

In addition, we collected data from samples of different ages across the experiments. In experiments 1, 2, 3, and 4, the mean age was balanced at around 20 years to limit the side effects of cybersickness in VR (Lithfous et al., 2014; Diersch & Wolbers, 2019) and the natural decline in spatial navigation strategies (Moffat et al., 2007; Lithfous et al., 2012; van der Ham et al., 2020). However, in Experiment 5, which involved VSWM, the average age of the participants was around 40 years. As age is a relevant predictor of navigation skills (van der Ham et al., 2020), these inconsistencies between studies should be further investigated. Future studies should consider recruiting participants with a more diverse age range in VR and spatial domain studies to test the validity of our conclusions.

Future studies should aim to improve the effectiveness of emotional stimuli. We presented static face, body, and environmental images on a two-dimensional screen. To maintain a high level of control over confounding variables and to facilitate comparison with existing literature, we chose perceptually clear and validated stimuli for these initial studies.

However, this approach may have limited the sense of presence, which affects the quality of a virtual reality experience, and the association with a more realistic and engaging context. To make the stimuli even more powerful, we can use multimodal elements such as dynamic facial expressions, voices, and videos to enhance the ecologically valid navigation.As such research could include avatars displaying anger while navigating an environment, or avatars running while expressing fear.

Another notable limitation was the lack of attention-related behavioural measures that often accompany VR and spatial navigation experiments, such as eye tracking. Since fearful and angry faces affect attention differently (Davis et al., 2011), its inclusion future studies could provide important insights into attentional patterns during spatial tasks and contribute to a more comprehensive understanding of the effects of facial emotional stimuli.

Another limitation is that we did not consider task-relevant emotional stimuli in our emotional manipulation. Since the comparison between relevant or irrelevant stimuli was not the focus of our investigations, we decided to use only task-irrelevant stimuli (in line with previous research, e.g., Gambarota & Sessa, 2019). Task irrelevance was also maintained across the three experiments to limit the influence of confounding variables, such as instructing participants to attend to emotions rather than allowing them to process emotions without being forced to do so. However, some theoretical accounts would argue against our findings, suggesting that emotions should be relevant to the task at hand in order to have an effect (e.g. appraisal theory, Mirabella et al., 2023). Therefore, although our findings provide initial evidence that task-irrelevant faces can indeed influence navigation and VSWM, we acknowledge that future studies could increase the relevance of the stimuli to investigate whether this modulates our findings.

Note that this approach could be particularly fruitful for investigating whether participants made an association between the task and the faces without being told. For example, fearful faces might be perceived as relevant to navigation by default (i.e., because of their association with threat avoidance) even without being asked to attend to the emotion, so that a comparison with a task-relevance condition might show no difference. In contrast, if relevance is a moderator, a more nuanced pattern might emerge. Furthermore, by comparing different types of stimuli, one might find that scenarios without any human reference (i.e., a dark forest) may have been ineffective because participants could not find an association (i.e., task-relevance) with the navigation task, and thus were less influential on final performance than faces (i.e., a human-social cue). This factor may have contributed to the null results in Experiment 3. Thus, future studies should address this issue more directly, possibly by comparing different types of stimuli (i.e., faces, bodies, scenes) in the same experiment for a more powerful investigation.

Besides, we focused on the use of negative rather than positive emotional expressions. Our choice was based on the potential of negative emotions to interfere with resource allocation, but also because negative emotions are likely to activate behavioural tendencies associated with their threat value (Öhman et al., 2001). By their very nature, they were particularly appropriate candidates for influencing the scope of navigation (i.e., reaching a destination without interference). However, it is worth considering the possibility of extending our effects to positive emotions (as we did in Experiment 3). In contrast to threatening emotions, they might encourage individuals to explore novel environments, whereas fear often promotes risk-averse behaviour and a preference for familiar and safe spaces (Basten et al., 2012). In line with this, previous research on visual working memory has demonstrated beneficial effects of positive facial expressions (Gonzales-Garrido et al., 2013). A promising avenue would be to test positive facial emotions in comparison to negative ones.

As a possible applied extension of this early research, our paradigm could be applied where training and simulation be fundamental, particularly in fields such as firefighting, policing, aviation, emergency response and the military, where spatial navigation (i.e. reaching a destination, often a safe place) and emotional regulation (in response to other's emotions) are crucial. These findings and our paradigms could be used to improve training programmes and design realistic simulation scenarios that incorporate emotional stimuli to better prepare individuals for real-life situations. For example, training protocols using VR and emotional stimulation could be developed to improve the ability of inexperienced professionals to navigate and respond effectively to emergency situations.

In terms of therapeutic interventions in the context of clinical psychology, our findings may suggest potential developments of virtual reality-based exposure therapies with emotional and social stimuli to increase treatment efficacy. Some clinical situations are often characterized by a combination of spatial and emotional information. As VR technology is now quite well developed, researchers have already explored its implications in the treatment of severe depression, anxiety, and phobias (Zeng et al., 2018; Garcia-Palacios et al., 2002). For example, individuals with posttraumatic stress disorder may experience intrusive and disturbing memories of highly distressing events, often with vivid spatial and emotional details that contribute to their emotional distress. Our findings may provide some useful information for professionals developing treatment protocols for such a sensitive population, for whom VR-based exposure is already a treatment protocol (Botella et al., 2015). In addition, our tasks can inspire researchers developing early diagnostic tools for patients with neurodegenerative diseases such as Alzheimer's, for which impaired navigation (i.e., disorientation) and emotion processing are early cognitive markers (Bucks & Radford, 2010; Coughlan et al., 2018).

5.4 **Conclusions**

This dissertation provided a first look at the effects of processing negative emotional stimuli on wayfinding, spatial navigation, and visuospatial processes. We used a variety of methods, ranging from virtual reality to cognitive tasks. Experiments consistently show that emotional faces, and especially fearful faces more than angry ones, can influence wayfinding behaviour, spatial navigation domains, and VSWM tasks. In most cases, the influence was detrimental, but mainly for males. We provided interpretations of the results based on differences in behavioural responses to the processing of fear and anger expressions, but also on differences between males and females in the management of their visuospatial cognitive resources. Finally, we suggested further research to build on our findings.

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APPENDIX

Appendix 1: Supplementary Materials 1: Pilot Study

We ran a pilot study with an identical design and procedure to that of the main study (see Methods section of the main text). We also collected the same exploratory variables of the main study at the end of the experimental session (see Supplementary Materials section about the exploratory variables) except for one variable (see Appendix 3). Data are available on OSF.

Participants

Twenty-three students were recruited as participants. Three female subjects were excluded due to cybersickness. The final sample consisted of 20 participants (9 males, M_{age} = 27.3, SD_{age} = 3.81; 11 females, M_{age} = 26.8, SD_{age} = 3.60).

Data Preparation and statistical Analyses

As for the main study, assumptions for parametric tests were not respected for both travel times and distance travelled, therefore we applied a logarithmic transformation of the data (see Table SM1.1 and Table SM1.2 for data before and after the transformation). We then ran a 3 (emotion: neutral vs. fearful vs. angry faces) x 2 (time: encoding vs. recalling) x 2 (gender: female vs. male) mixed ANOVA on the two dependent variables.

Results

Results are reported in Table SM1.3. For both dependent variables, the only significant effect is that of time, showing that participants improved their performances the second time they entered the virtual environment. Although the three-way interaction between emotions, time, and gender was not significant, we can interpret the descriptive pattern. The emotion manipulations, both anger and fear, slightly reduced the performances of male participants with respect to the neutral condition and slightly increased that of females. Comparing the two genders, we observe that the performance of male participants decreases after the two emotional manipulations with respect to females, but it is higher in the neutral condition. Because these were preliminary data and collected on a limited sample, we conducted the main study in which we doubled the sample size.

Table SM1.1 Means and standard deviation (in parenthesis) of travel time in seconds and travelled distances expressed in unit measures of the interaction between gender and the three emotional manipulations for the pilot study.

Times	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	104 (54.0)	60.9 (22.0)	43.2 (56.1)	147 (103)	53.4 (26.1)	93.9 (112)
Fear	123 (67.5)	49.5 (18.1)	73.5 (62.8)	60.0 (19.5)	48.1 (38.5)	11.9 (46.7)
Anger	112 (52.2)	60.8 (55.1)	61.1 (49.8)	67.1 (36.2)	44.6 (23.9)	22.6 (44.0)
Distances	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	96.6 (40.8)	80.6 (29.8)	16.0 (37.7)	214 (123)	99.1 (49.5)	114.9 (163)
Fear	115 (58.3)	63.6 (17.2)	51.0 (64.8)	95.8 (28.9)	94.9 (94.7)	0.90 (102.0)
Anger	127 (69.5)	79.7 (74.4)	46.8 (72.8)	105 (58.5)	84.4 (50.2)	21.1 (79.5)

Table SM1.2 Means and standard deviation (in parenthesis) of travel time in seconds and travelled distances expressed in unit measures of the interaction between gender and the three emotional manipulations for the pilot study after the logarithmic transformation.

Times (log)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	4.51 (.56)	4.05 (.34)	.45 (.57)	4.76 (.73)	3.82 (.66)	.94 (1.10)
Fear	4.67 (.57	3.83 (.41)	.84 (.58)	4.05 (.30)	3.66 (.65)	.38 (.76)
Anger	4.71 (.46)	3.86 (.67)	.84 (.50)	4.10 (.48)	3.67 (.56)	.42 (.75)
Distances (log)	*Female*			*Male*		
Emotion	T1	T2	T1-T2	T1	T2	T1-T2
Neutral	4.50 (.39)	4.34 (.33)	.16 (.40)	5.21 (.60)	4.46 (.58)	.75 (1.12)
Fear	4.63 (.49)	4.12 (.27)	.51 (.59)	4.52 (.31)	4.30 (.67)	.22 (.76)
Anger	4.71 (.53)	4.17 (.59)	.54 (.71)	4.56 (.44)	4.30 (.53)	.26 (.71)

Table SM1.3 Results of the Statistical Analysis on Behavioral outcomes of the Pilot Study.

Variable	Effect	Factors	*df*	*F*	*p*	ES
Time	Main	Time	1, 18	44.6	**.001**	.71
	Main	Gender	1, 18	3.73	.06	.17
	Main	Emotion	2, 36	2.69	.08	.13
	Interaction	Time x Gender	1, 18	.42	.52	.02
	Interaction	Time x Emotion	2, 36	.08	.92	.005
	Interaction	Emotion x Gender	2, 36	2.32	.11	.11
	Interaction	T x G x E	2, 36	2.81	.07	.13
Distances	Main	Time	1, 18	17.7	**.001**	.50
	Main	Gender	1, 18	2.89	.10	.14
	Main	Emotion	2, 36	2.61	.08	.13
	Interaction	Time x Gender	1, 18	.001	.97	.000
	Interaction	Time x Emotion	2, 36	.08	.92	.005
	Interaction	Emotion x Gender	2, 36	2.27	.12	.11
	Interaction	T x G x E	2, 36	2.70	.08	.13

Supplementary Materials 2: Assumptions Check of the Pilot Study

We checked whether the assumptions of parametric tests (i.e., mixed ANOVA) were respected in our data. We report here the results. Since for both our dependent variables, travel times and distance travelled, they were not respected (see table and figure SM2.1, SM2.3), we proceeded to transform the data to normalize the distributions. We then checked again the assumptions and they were respected (see table and figure SM2.2, SM2.4). Note that in the tables' variables names: N stands for Neutral, F for Fear, and A for Anger, 1 for T1, and 2 for T2, unless otherwise stated.

SM2.1 Assumptions Travel Time Pre-Transformation

Tests of Sphericity.

	Mauchly's W	*p*	*Greenhouse-Geisser ε*	*Huynh-Feldt ε*
Emotion	0.974	0.802	0.975	1.000
Time	1.000	NaN [a]	1.000	1.000
Emotion ✻ Time	0.815	0.176	0.844	0.922

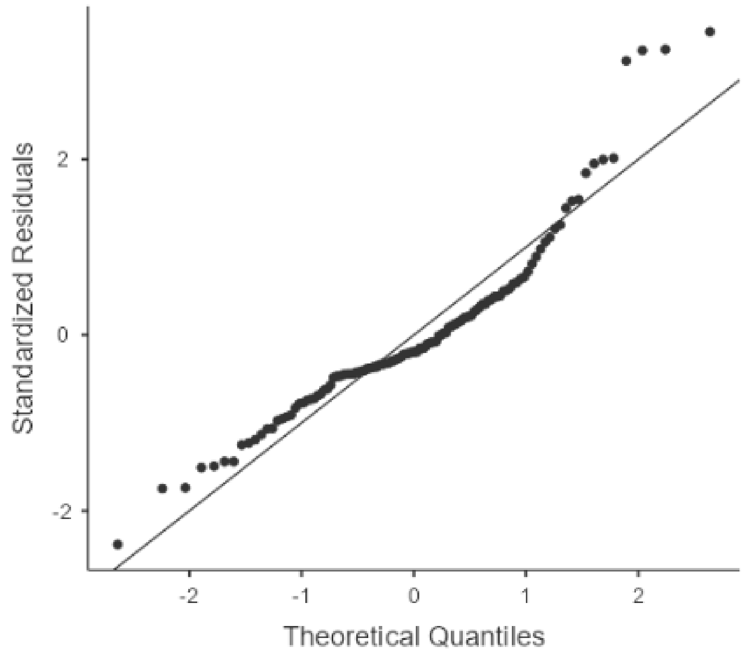
Homogeneity of Variances Test (Levene's)

	F	*df1*	*df2*	*p*
N1	6.219	1	18	0.023
N2	0.758	1	18	0.395
F1	7.049	1	18	0.016
F2	1.622	1	18	0.219
A1	2.813	1	18	0.111
A2	1.474	1	18	0.240

Shapiro Wilk test on the cells of 2x2x3 Mixed ANOVA checking the normality of the distributions.

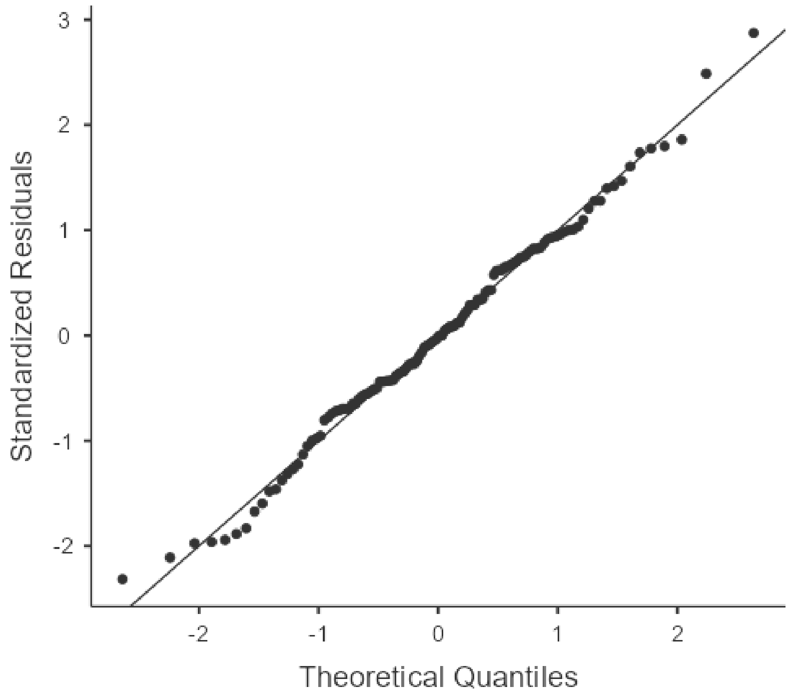
	Gender	*N1*	*N2*	*F1*	*F2*	*A1*	*A2*
W	F	0.929	0.801	0.934	0.976	0.926	0.675
	M	0.854	0.736	0.889	0.738	0.799	0.907
p	F	0.398	0.010	0.447	0.942	0.370	< .001
	M	0.083	0.004	0.193	0.004	0.020	0.293

Q-Q Plot



SM2.2 Assumptions Travel Time Post Log Transformation

Q-Q Plot



Tests of Sphericity.

	Mauchly's W	*p*	*Greenhouse-Geisser ε*	*Huynh-Feldt ε*
Emotions	0.976	0.814	0.977	1.000
Time	1.000	NaN [a]	1.000	1.000
Emotions ✻ Time	0.769	0.107	0.812	0.881

Homogeneity of Variances Test (Levene's).

	F	*df1*	*df2*	*p*
N1 - Log	0.7655	1	18	0.393
N2 - Log	11.7869	1	18	0.003
F1 - Log	4.3429	1	18	0.052
F2 - Log	1.1135	1	18	0.305
A1 - Log	0.1214	1	18	0.732
A2 - Log	0.0887	1	18	0.769

Shapiro Wilk test on the cells of 2x2x3 Mixed ANOVA checking the normality of the distributions.

	Gender	*N1*	*N2*	*F1*	*F2*	*A1*	*A2*
W	F	0.958	0.827	0.979	0.946	0.954	0.934
	M	0.946	0.708	0.936	0.947	0.905	0.961
p	F	0.744	0.021	0.959	0.598	0.698	0.457
	M	0.644	0.002	0.544	0.654	0.282	0.810

SM2.3 Assumptions Distance Travelled Pre-Transformation

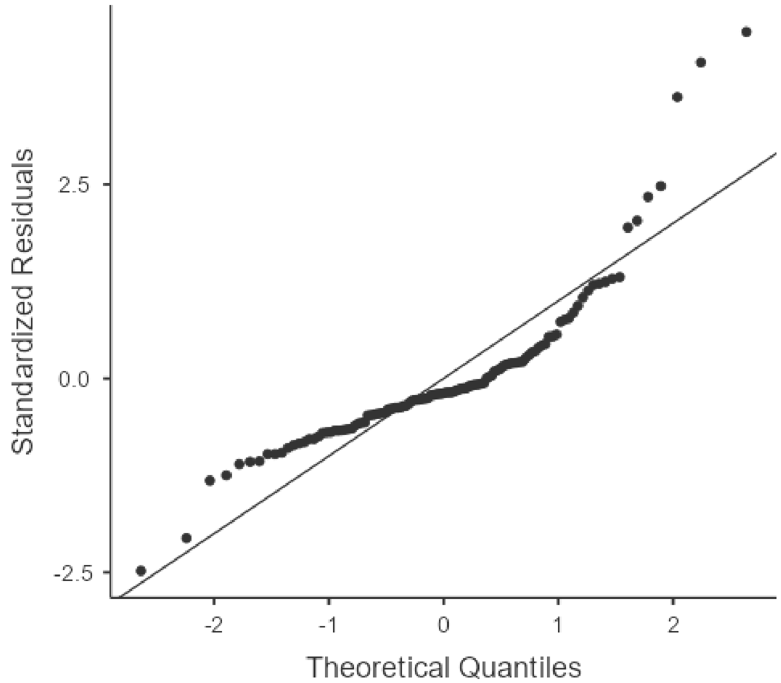
Tests of Sphericity.

	Mauchly's W	*p*	*Greenhouse-Geisser ε*	*Huynh-Feldt ε*
Emotions	0.970	0.773	0.971	1.000
Time	1.000	NaN [a]	1.000	1.000
Emotions ✻ Time	0.765	0.102	0.809	0.878

Homogeneity of Variances Test (Levene's).

	F	*df1*	*df2*	*p*
N1	3.6486	1	18	0.072
N2	8.2558	1	18	0.010
F1	4.1328	1	18	0.057
F2	4.0050	1	18	0.061
A1	1.2409	1	18	0.280
A2	0.0863	1	18	0.772

Q-Q Plot on the residuals of the 2x2x3 Mixed ANOVA for the normality of residuals.



Shapiro Wilk test on the cells of 2x2x3 Mixed ANOVA checking the normality of the distributions.

	Gender	*N1*	*N2*	*F1*	*F2*	*A1*	*A2*
W	F	0.833	0.830	0.894	0.960	0.893	0.556
	M	0.900	0.857	0.950	0.598	0.638	0.839
p	F	0.026	0.023	0.155	0.774	0.152	< .001
	M	0.255	0.089	0.688	< .001	< .001	0.057

SM2.4 Assumptions Distance Travelled Post-Transformation

Tests of Sphericity.

	Mauchly's W	*p*	*Greenhouse-Geisser ε*	*Huynh-Feldt ε*
Emotions	0.809	0.165	0.840	0.916
Time	1.000	NaN [a]	1.000	1.000
Emotions ✻ Time	0.741	0.078	0.794	0.859

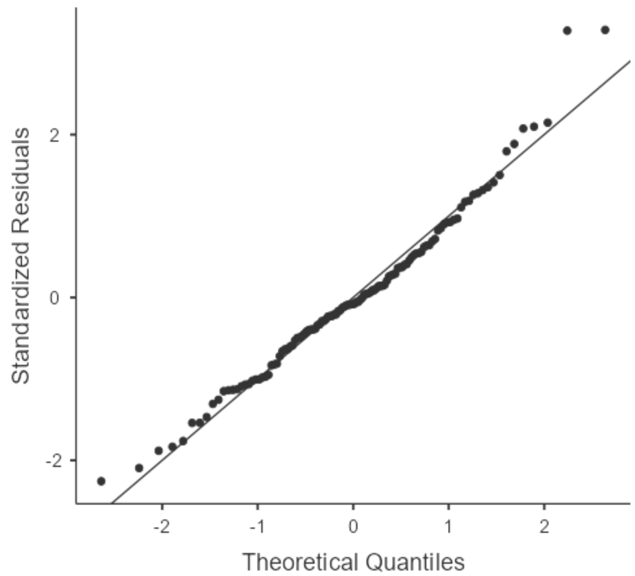
Homogeneity of Variances Test (Levene's).

	F	*df1*	*df2*	*p*
N1 - Log	1.4891	1	18	0.238
N2 - Log	9.7030	1	18	0.006
F1 - Log	2.6105	1	18	0.124
F2 - Log	2.5588	1	18	0.127
A1 - Log	1.3399	1	18	0.262
A2 - Log	0.0134	1	18	0.909

Shapiro Wilk test on the cells of 2x2x3 Mixed ANOVA checking the normality of the distributions.

	Gender	*N1*	*N2*	*F1*	*F2*	*A1*	*A2*
W	F	0.911	0.911	0.935	0.970	0.966	0.824
	M	0.956	0.860	0.961	0.853	0.799	0.984
p	F	0.252	0.253	0.468	0.882	0.848	0.020
	M	0.756	0.096	0.807	0.080	0.020	0.981

Q-Q Plot on the residuals of the 2x2x3 Mixed ANOVA for the normality of residuals.



Appendix 2: Supplementary Materials 3: Assumptions Check of Experiment 1

We checked whether the assumptions of parametric tests (i.e., mixed ANOVA) were respected in our data. We report here the results. Since for both our dependent variables, travel times and distance travelled, they were not respected (see table and figure SM3.1, SM3.3), we proceeded to transform the data to normalize the distributions. We then checked again the assumptions and they were respected (see table and figure SM3.2, SM3.4). Note that in the tables' variables names: N stands for Neutral, F for Fear, and A for Anger, 1 for T1, and 2 for T2, unless otherwise stated.

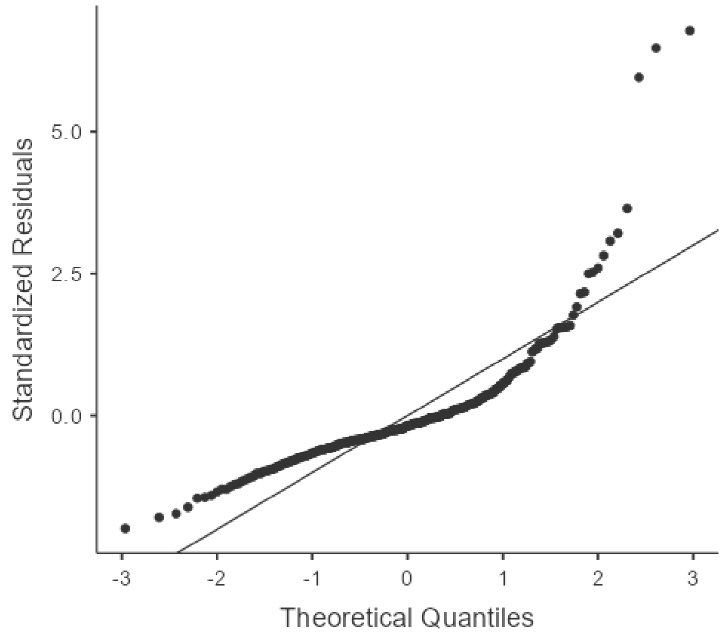
SM3.1 Assumptions Travel Time Pre-Transformation

Tests of Sphericity.

	Mauchly's W	*p*	*Greenhouse-Geisser ε*	*Huynh-Feldt ε*
Emotions	0.893	0.052	0.903	0.933
Time	1.000	NaN [a]	1.000	1.000
Emotions ✻ Time	0.891	0.050	0.902	0.932

Homgeneity of Variances Test (Levene's).

	F	*df1*	*df2*	*p*
N1	0.216	1	53	0.644
N2	2.585	1	53	0.114
F1	10.356	1	53	0.002
F2	0.242	1	53	0.625
A1	3.075	1	53	0.085
A2	6.632	1	53	0.013



Shapiro Wilk test on the cells of 2x2x3 Mixed ANOVA checking the normality of the distributions.

	Gender	*N1*	*N2*	*F1*	*F2*	*A1*	*A2*
W	F	0.648	0.860	0.804	0.658	0.906	0.641
	M	0.795	0.741	0.941	0.866	0.819	0.862
p	F	< .001	< .001	< .001	< .001	0.010	< .001
	M	< .001	< .001	0.168	0.004	< .001	0.004

SM3.2 Assumptions Time Travel Post Transformation

Tests of Sphericity

	Mauchly's W	*p*	*Greenhouse-Geisser ε*	*Huynh-Feldt ε*
Emotions	1.000	0.992	1.000	1.000
Time	1.000	NaN [a]	1.000	1.000
Emotions ✻ Time	0.912	0.092	0.919	0.951

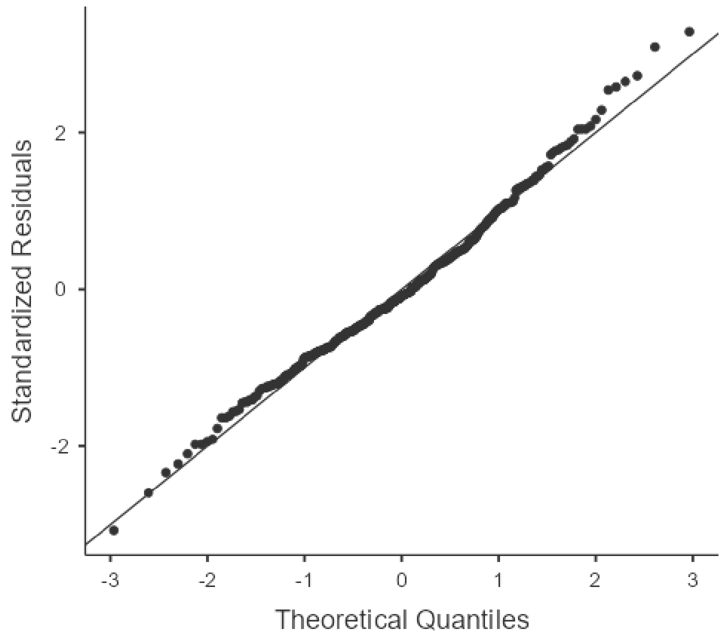
Homogeneity of Variances Test (Levene's)

	F	*df1*	*df2*	*p*
N1 - Log	1.141	1	53	0.290
N2 - Log	0.345	1	53	0.560
F1 - Log	0.280	1	53	0.599
F2 - Log	0.912	1	53	0.344
A1 - Log	0.507	1	53	0.480
A2 - Log	3.849	1	53	0.055

Shapiro Wilk test on the cells Mixed ANOVA checking the normality of the distribution.

	Gender	*N1 - Log*	*N2 - Log*	*F1 - Log*	*F2 - Log*	*A1 - Log*	*A2 - Log*
W	F	0.931	0.985	0.988	0.944	0.973	0.917
	M	0.933	0.917	0.948	0.933	0.975	0.982
p	F	0.046	0.938	0.975	0.105	0.619	0.020
	M	0.113	0.049	0.246	0.114	0.779	0.935

Q-Q Plot on the residuals of the 2x2x3 Mixed ANOVA for the normality of residuals.



SM3.3 Assumptions Distance Travelled Pre-Transformation

Tests of Sphericity

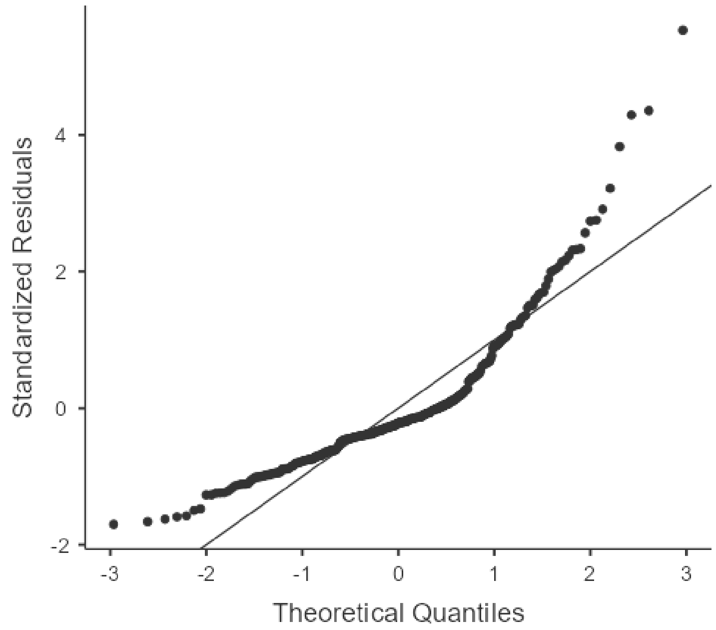
	Mauchly's W	*p*	*Greenhouse-Geisser ε*	*Huynh-Feldt ε*
Emotions	0.993	0.836	0.993	1.000
Time	1.000	NaN [a]	1.000	1.000
Emotions ✻ Time	0.941	0.205	0.944	0.978

Homogeneity of Variances Test (Levene's)

	F	*df1*	*df2*	*p*
N1-DIST	0.00170	1	53	0.967
N2-DIST	0.75549	1	53	0.389
F1-DIST	7.07865	1	53	0.010
F2-DIST	6.69291	1	53	0.012
A1-DIST	0.02119	1	53	0.885
A2-DIST	0.25861	1	53	0.613

Shapiro Wilk test on the cells of 2x2x3 Mixed ANOVA checking the normality of the distributions.

	Gender	*N1*	*N2*	*F1*	*F2*	*A1*	*A2*
W	F	0.776	0.816	0.923	0.706	0.885	0.615
	M	0.810	0.695	0.907	0.871	0.870	0.711
p	F	< .001	< .001	0.028	< .001	0.003	< .001
	M	< .001	< .001	0.031	0.006	0.005	< .001



Q-Q Plot on the residuals of the 2x2x3 Mixed ANOVA for the normality of residuals.

SM3.4 Assumptions Distance Travelled Post Transformation

Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
Emotions	0.974	0.508	0.975	1.000
Time	1.000	NaN [a]	1.000	1.000
Emotions ✻ Time	0.934	0.169	0.938	0.971

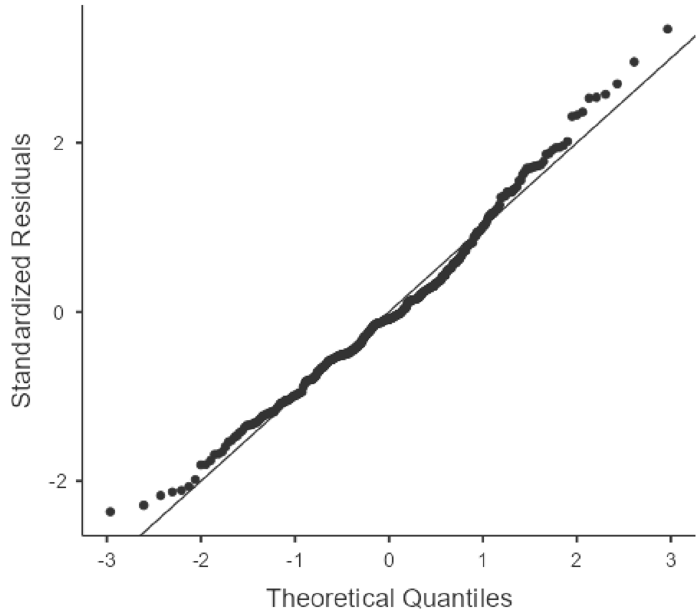
Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
N1-DIST - Log	0.394	1	53	0.533
N2-DIST - Log	0.185	1	53	0.669
F1-DIST - Log	1.572	1	53	0.215
F2-DIST - Log	3.741	1	53	0.058
A1-DIST - Log	0.322	1	53	0.573
A2-DIST - Log	0.284	1	53	0.597

Shapiro Wilk test on the cells of 2x2x3 Mixed ANOVA checking the normality of the distributions.

	Gender	N1-DIST - Log	N2-DIST - Log	F1-DIST - Log	F2-DIST - Log	A1-DIST - Log	A2-DIST - Log
W	F	0.971	0.962	0.968	0.924	0.940	0.885
	M	0.967	0.899	0.981	0.928	0.976	0.904
p	F	0.547	0.322	0.469	0.031	0.083	0.003
	M	0.597	0.021	0.913	0.089	0.813	0.026

Q-Q Plot on the residuals of the 2x2x3 Mixed ANOVA for the normality of residual



Appendix 3: Supplementary Materials 4: Exploratory Variable

In both the pilot study and Experiment 1, we focused on exploratory variables to explore the characteristics of our sample and to inspect potentially interesting relationships between navigation, emotions, and individual characteristic. The questionnaires were administered at the end of the experimental phase to not affect the outcome of our main results. We report here a description of the measures, the descriptive analyses results, and a partial correlation table separated for male and female participants.

Materials

Pilot and Main study

Simulator Sickness Questionnaire (SSQ; Walter et al., 2019). To evaluate cybersickness related to the VR tasks, participants rated the severity of each symptom (e.g., nausea, headache, sweating) on a 4-point Likert scale (0 "None" to 3 "Severe") using the 16 items of the The SSQ provided four representative sub-scores: nausea-related (N), oculomotor-related (O), disorientation-related (D), and a total score (TS). *Autism Spectrum Quotient scale* (AQ; Baron-Cohen et al., 2005). We included this measure to explore the potential relationship of the presence of autistic traits with wayfinding behaviours and navigation after our emotional manipulations. In autism, navigation is atypical as well as emotion processing (Ring et al., 2018; Baron-Cohen et al., 2005) and individuals with high autistic traits may share the same characteristic. Therefore, it seemed plausible to us that participants with high autistic traits might also be less performant in navigation even before the emotional exposure. The AQ questionnaire consists of 50 items. The AQ can identify individuals who may not meet diagnostic criteria for autism, but who exhibit high autistic traits that may influence the effect of being exposed to emotional stimuli since, in autism, emotional processing is often atypical or reduced. All our participants were below the cut-off level set by the developers thought to indicate a higher risk and probability to meet the criteria for the diagnosis of autism.

Pilot study

Depression, Anxiety, Stress State scale (DASS-21; Samani & Joukar, 2007; Medvedev, 2023). We explored the relationship between self-reported emotional states and the results of our experiment. For measuring the emotional states of stress, anxiety, and depression. The short version of the DASS is a set of three self-report scales, based on a dimensional rather than a categorical conception of each psychological disorder. Each of the three scales contains 7 items, divided into subscales with similar content. The depression scale assessed dysphoria, hopelessness, devaluation of life, self- deprecation, lack of interest/involvement, anhedonia, and inertia. The anxiety scale assessed autonomic arousal, skeletal muscle effects, situational anxiety, and subjective experience of anxious affect. While the stress scale assessed difficulty relaxing, nervous arousal, and being easily upset/agitated, irritable/over-reactive and impatient.

Experiment 1

Wayfinding Questionnaire (WQ; Claessen & de Rooij, et al., 2016). The questionnaire was used to assess participants' self-reported navigation abilities. It contains 22 items divided into three subscales: navigation and orientation (11 items), distance estimation (3 items), and spatial anxiety (8 items). Refer to Claessen et al. 2016 for scoring rules.

Results

Pilot Study

The correlation table shows that for female participants there is no correlation between exploratory variables and both time travel and distances travelled. For male participants, there is a negative association between the subscale's "depression" and "anxiety" of the DASS-21 and the performance in the fear condition, such that higher scores in depression and anxiety were associated with lower performances in fear.

Experiment 1

The correlation table shows that for female participants there is a positive association between simulation sickness (SSQ) and distance travelled in the fear condition, but not with any other conditions. For male participants, there is a negative association between the subscales "orientation and navigation" and "distance estimation" of the WQ and the performance in the fear condition, this means that higher scores in the variables were associated with a decrease in performance after the fear exposure. Also, there was a positive association between the subscale spatial anxiety and the performance in the neutral condition.

Discussion

These data were collected to explore the possible patterns of correlations between navigation, emotions, and psychological self-reported measures. Our results suggest that emotional and wayfinding self-reported characteristics of participants correlated with some of the results we obtained in males but not in female participants. Males are also the participants that were most affected by our emotion conditions (see Main Text for details). For this reason, future studies should systematically investigate the implications of these variables for navigation and emotion processing.

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Table SM4.1. Descriptive analysis of the exploratory variables of the Pilot study

	Gender	Age	SSQ	AQ	DASS-21 Depression	DASS-21 Anxiety	DASS- 21 Stress
N	F	11	11	11	11	11	11
	M	9	9	9	9	9	9
Missing	F	0	0	0	0	0	0
	M	0	0	0	0	0	0
Mean	F	26.8	62.6	13.0	11.8	8.73	14.4
	M	27.3	39.1	16.2	10.0	6.67	18.9
Median	F	27	48.6	12	12	8	12
	M	26	26.2	16	8	4	18
Standard deviation	F	3.60	42.2	5.39	5.40	7.76	7.15
	M	3.81	34.9	4.02	6.56	8.60	7.88
Minimum	F	20	11.2	3	0	0	2
	M	24	3.74	8	2	0	4
Maximum	F	33	146	21	20	30	30
	M	37	112	22	24	24	30

Table SM4.1. Descriptive analysis of the exploratory variables of Experiment 1.

	Gender	Age	SSQ	AQ	WQ A	WQB	WQC
N	F	31	30	31	31	31	31
	M	24	24	24	24	24	24
Missing	F	21.5	40.9	16.1	50.5	34.2	9.90
	M	23.5	19.3	18.5	58.5	39.3	13.8
Mean	F	22	37.4	16	49	34	10
	M	23.0	18.7	18.5	61.0	39.0	13.5
Median	F	2.55	24.2	5.98	10.3	9.91	4.35
	M	2.72	14.5	6.60	11.9	8.45	4.08
Standard deviation	F	18	3.74	4	27	17	3
	M	19	0.00	6	31	22	7
Minimum	F	28	97.2	30	72	56	20
	M	29	56.1	32	76	56	21
Maximum	F	31	30	31	31	31	31
	M	24	24	24	24	24	24

Table SM4.3. Female participants. Partial correlation table including the experimental dependent variables and the exploratory variables of the pilot study.

	AGE	RT-N	RT-F	RT-A	D-N	D-F	D-A	DASS-1	DASS-2	DASS-3	AQ	SSQ
AGE	—											
RT-N	-0.062	—										
RT-F	-0.239	0.156	—									
RT-A	-0.305	-0.582	-0.198	—								
D-N	0.054	0.953 ***	0.115	-0.645 *	—							
D-F	-0.266	-0.015	0.952 ***	-0.129	-0.001	—						
D-A	-0.432	-0.581	-0.118	0.896 ***	-0.581	0.026	—					
DASS-1	0.039	0.196	0.233	-0.023	0.209	0.189	-0.191	—				
DASS-2	-0.482	0.167	0.162	0.290	0.158	0.239	0.406	0.443	—			
DASS-3	-0.293	0.156	0.104	0.128	0.131	0.142	0.075	0.810 **	0.817 **	—		
AQ	-0.144	0.228	0.385	-0.248	0.178	0.262	-0.408	0.750 **	0.101	0.520	—	
SSQ	-0.151	0.051	-0.365	0.196	0.064	-0.402	0.151	0.321	-0.043	0.125	0.202	—

Table SM4.4. Male participants. Partial correlation table including the experimental dependent variables and the exploratory variables of the pilot study.

	AGE	RT-N	RT-F	RT-A	D-N	D-F	D-A	DASS1	DASS2	DASS3	AQ	SSQ
AGE	—											
RT-N	-0.294	—										
RT-F	0.142	-0.074	—									
RT-A	-0.191	-0.006	0.729 *	—								
D-N	-0.256	0.984 ***	-0.105	0.006	—							
D-F	0.017	-0.087	0.975 ***	0.710 *	-0.136	—						
D-A	-0.114	0.024	0.803 **	0.972 ***	0.052	0.781 *	—					
DASS1	-0.370	-0.138	-0.798 **	-0.416	-0.093	-0.762 *	-0.508	—				
DASS2	-0.321	-0.232	-0.766 *	-0.636	-0.210	-0.701 *	-0.689 *	0.913 ***	—			
DASS3	-0.178	-0.343	-0.438	-0.379	-0.331	-0.460	-0.457	0.774 *	0.816 **	—		
AQ	-0.707 *	-0.082	-0.429	-0.299	-0.124	-0.349	-0.409	0.540	0.660	0.576	—	
SSQ	-0.033	0.100	0.176	0.084	0.174	0.033	0.123	-0.057	-0.017	0.289	0.253	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. T = travel times (T1-T2), D = distance travelled (T1-T2), N = neutral, F = fear, A = Anger, DASS-1 = Depression, DASS-2 = Anxiety, DASS-3 = Stress, AQ = Autism Spectrum Quotient scale, SSQ = Simulator Sickness Questionnaire

Table SM4.5. Female participants. Partial correlation table including the experimental dependent variables and the exploratory variables of the Experiment 1.

	AGE	T-N	T-F	T-A	D-N	D-F	D-A	WQ1	WQ2	WQ3	AQ	SSQ
AGE	—											
T-N	0.226	—										
T-F	0.004	-0.069	—									
T-A	-0.103	0.178	-0.546 **	—								
D-N	0.128	0.839 ***	-0.036	0.113	—							
D-F	0.028	-0.111	0.901 ***	-0.504 **	-0.102	—						
D-A	0.042	0.143	-0.526 **	0.804 ***	0.073	-0.452 *	—					
WQ1	0.036	0.160	0.058	0.174	-0.000	0.083	0.099	—				
WQ2	0.242	0.228	0.288	-0.018	0.167	0.190	0.144	0.360 *	—			
WQ3	0.211	0.092	0.129	-0.301	0.032	0.255	-0.350	0.576 ***	0.109	—		
AQ	-0.148	0.251	0.105	-0.143	0.219	-0.015	-0.093	-0.245	0.085	-0.257	—	
SSQ	0.368 *	-0.329	0.361	-0.352	-0.263	0.399 *	-0.101	-0.062	0.015	0.112	-0.246	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. T = travel times (T1-T2), D = distance travelled (T1-T2), N = neutral, F = fear, A = Anger, WQ1 = orientation and navigation, WQ2 = spatial anxiety, WQ3 = distance estimation, AQ = Autism Spectrum Quotient scale, SSQ = Simulator Sickness Questionnaire.

Table SM4.6. Male participants. Partial correlation table including the experimental dependent variables and the exploratory variables of Experiment 1

	AGE	T-N	T-F	T-A	D-N	D-F	D-A	WQ1	WQ2	WQ3	AQ	SSQ
AGE	—											
T-N	0.229	—										
T-F	-0.105	-0.049	—									
T-A	-0.325	0.168	0.642 ***	—								
D-N	0.197	0.929 ***	-0.203	0.110	—							
D-F	-0.161	-0.000	0.972 ***	0.726 ***	-0.152	—						
D-A	-0.180	0.062	0.640 ***	0.806 ***	0.022	0.734 ***	—					
WQ1	0.017	0.313	-0.465 *	0.054	0.378	-0.359	-0.014	—				
WQ2	-0.137	0.544 **	-0.317	0.146	0.499 *	-0.201	0.040	0.676 ***	—			
WQ3	-0.140	-0.021	-0.652 ***	-0.188	-0.002	-0.520 **	-0.184	0.747 ***	0.625 **	—		
AQ	0.012	-0.339	0.110	0.068	-0.344	0.023	-0.165	-0.098	-0.316	-0.131	—	
SSQ	0.191	-0.272	0.092	0.021	-0.275	0.102	0.104	-0.293	-0.184	-0.061	0.194	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. T = travel times (T1-T2), D = distance travelled (T1-T2),N = neutral, F = fear, A = Anger, WQ1 = orientation and navigation, WQ2 = spatial anxiety, WQ3 = distance estimation, AQ = Autism Spectrum Quotient scale, SSQ = Simulator Sickness Questionnaire.

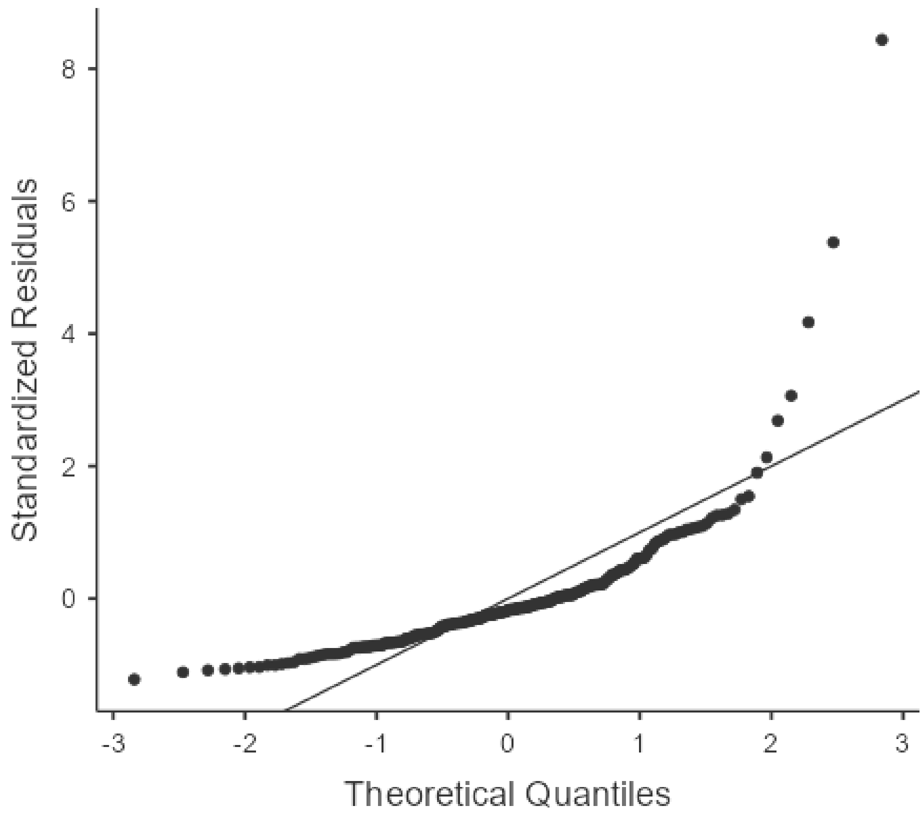
Appendix 4: Supplementary Materials 4: Assumptions Experiment 2: Bodies
Assumptions Travel Times Before the logarithmic transformation

Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
EMOTIONS	0.674	0.001	0.754	0.781
Times	1.000	NaN [a]	1.000	1.000
EMOTIONS ✻ Times	0.531	< .001	0.681	0.699

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
N1	0.0905	1	35	0.765
N2	3.0798	1	35	0.088
F1	0.0955	1	35	0.759
F2	0.9122	1	35	0.346
A1	2.7271	1	35	0.108
A2	1.7112	1	35	0.199



Assumptions Experiment 2: BODIES Travel Times After the logarithmic transformation

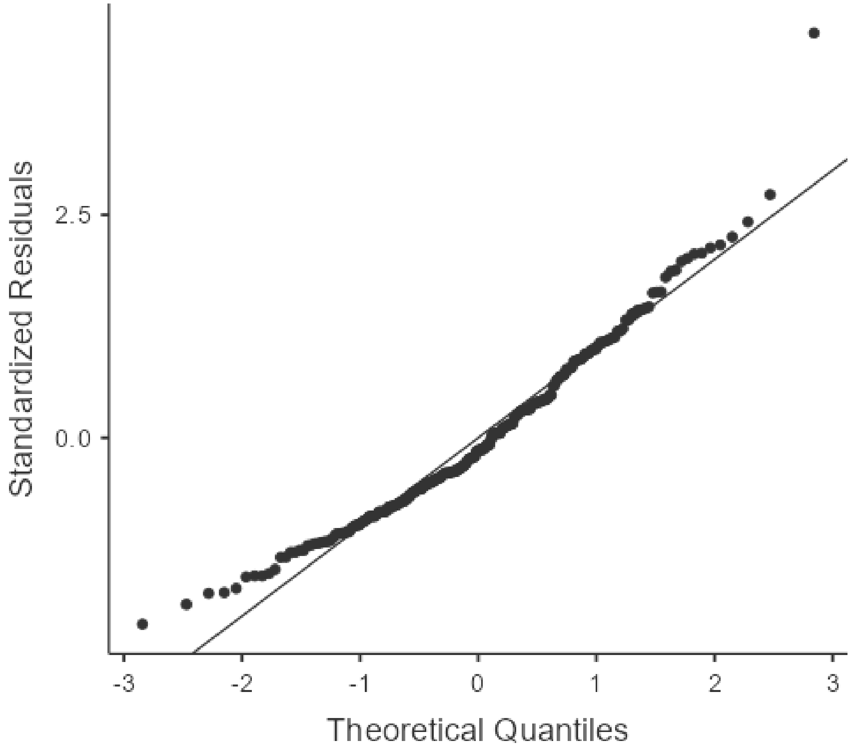
Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
EMOTIONS	0.906	0.188	0.914	0.962
Times	1.000	NaN [a]	1.000	1.000
EMOTIONS ✻ Times	0.787	0.017	0.824	0.860

[a] The repeated measures has only two levels. The assumption of sphericity is always met when the repeated measures has only two levels.

Homogeneity of Variances Test (Levene's)

	F	df1	df2	P
N1 - Log	0.172	1	35	0.681
N2 - Log	1.395	1	35	0.246
F1 - Log	1.808	1	35	0.187
F2 - Log	1.902	1	35	0.177
A1 - Log	0.268	1	35	0.608
A2 - Log	1.702	1	35	0.201



Assumptions Experiment 2: BODIES Distances Travelled Before the logarithmic transformation

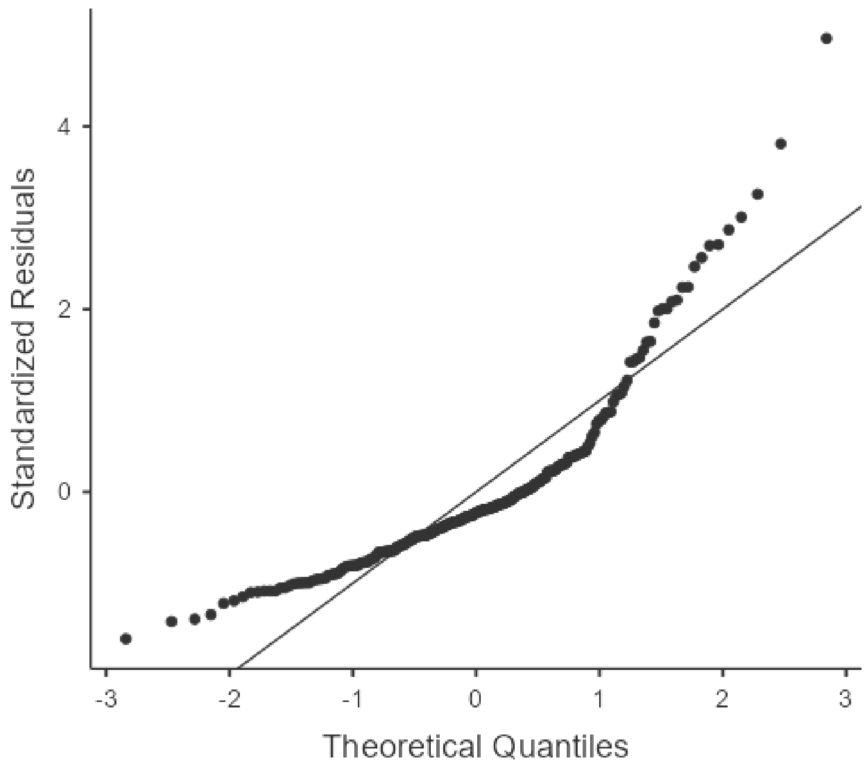
Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
EMOTIONS	0.806	0.025	0.837	0.874
Times	1.000	NaN [a]	1.000	1.000
EMOTIONS ✻ Times	0.849	0.062	0.869	0.910

[a] The repeated measures has only two levels. The assumption of sphericity is always met when the repeated measures has only two levels.

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
DN1	0.0136	1	35	0.908
DN2	2.3724	1	35	0.132
DF1	0.3093	1	35	0.582
DF2	3.4643	1	35	0.071
DA1	0.2900	1	35	0.594
DA2	0.0195	1	35	0.890



Assumptions Experiment 2: BODIES Distances Travelled After the logarithmic transformation

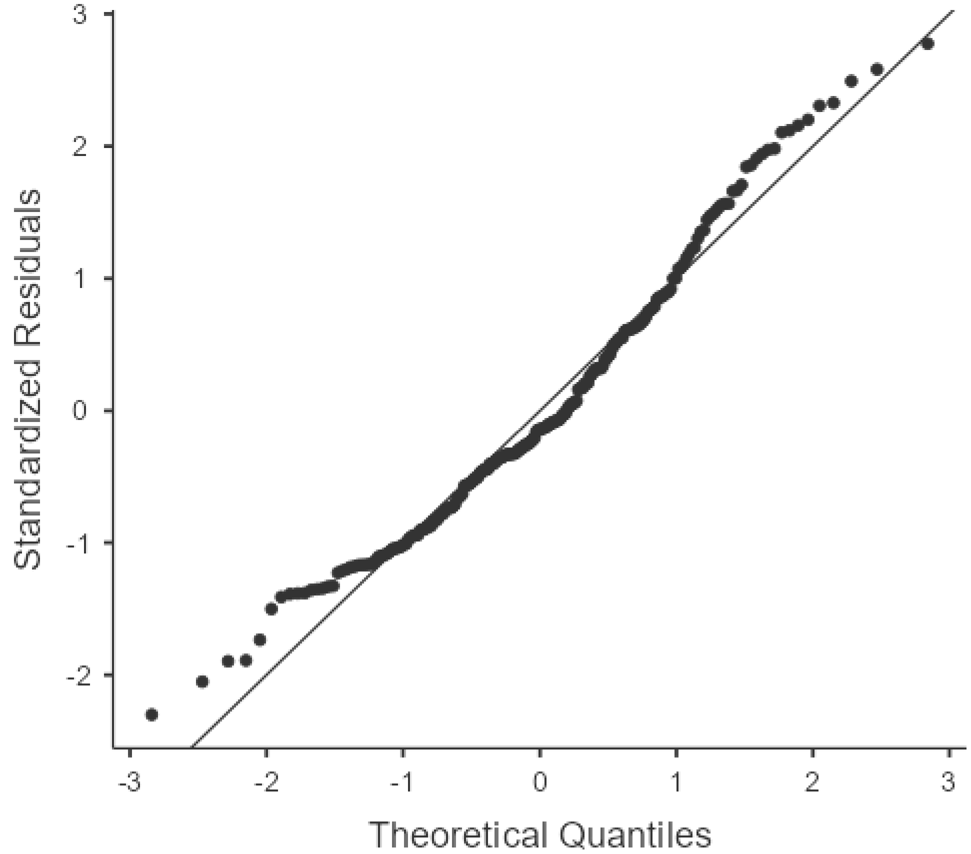
Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
EMOTIONS	0.929	0.286	0.934	0.984
Times	1.000	NaN [a]	1.000	1.000
EMOTIONS ✻ Times	0.861	0.079	0.878	0.921

[a] The repeated measures has only two levels. The assumption of sphericity is always met when the repeated measures has only two levels.

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
DN1 - Log	8.20e-4	1	35	0.977
DN2 - Log	1.4120	1	35	0.243
DF1 - Log	0.5429	1	35	0.466
DF2 - Log	3.0656	1	35	0.089
DA1 - Log	0.2774	1	35	0.602
DA2 - Log	0.0332	1	35	0.856



Appendix 5: Supplementary Materials 5: Assumptions Experiment 3 Scenes

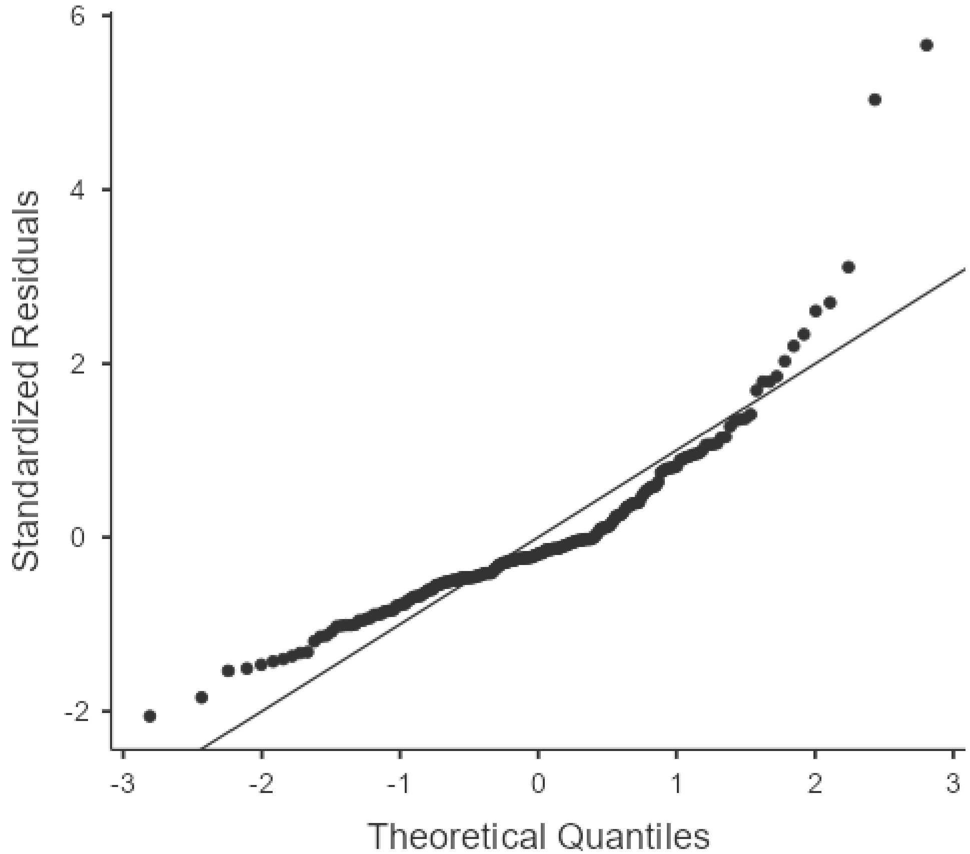
Assumptions Experiment 3: SCENES Travel Times Before the logarithmic transformation

Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
Emotional Scenarios	1.00	NaN [a]	1.00	1.00
VR Sessions	1.00	NaN [a]	1.00	1.00
Emotional Scenarios ✻ VR Sessions	1.00	NaN [a]	1.00	1.00

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
R1	1.492	1	48	0.228
R2	16.210	1	48	< .001
T1	4.526	1	48	0.039
T2	0.848	1	48	0.362



Assumptions Experiment 3: SCENES Travel Times After the logarithmic transformation

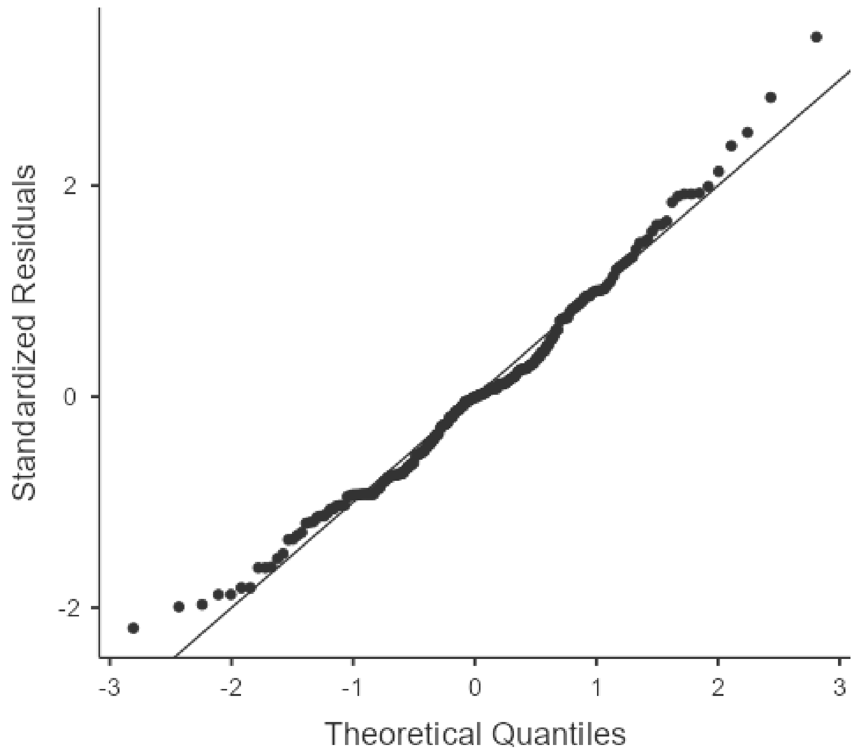
Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
Emotional Scenarios	1.00	NaN [a]	1.00	1.00
VR Sessions	1.00	NaN [a]	1.00	1.00
Emotional Scenarios ✻ VR Sessions	1.00	NaN [a]	1.00	1.00

[a] The repeated measures has only two levels. The assumption of sphericity is always met when the repeated measures has only two levels

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
R1_LOG	0.214	1	48	0.646
R2_LOG	6.533	1	48	0.014
T1_LOG	0.830	1	48	0.367
T2_LOG	0.280	1	48	0.599



Assumptions Experiment 3: SCENES Distances Travelled Before the logarithmic transformation.

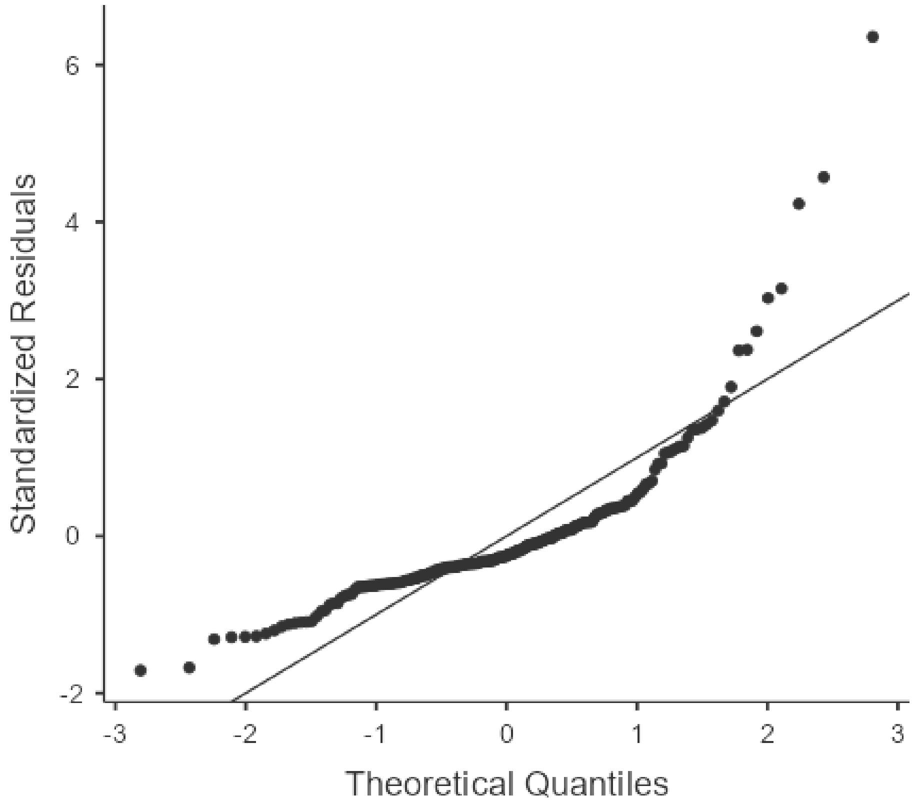
Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
Emotional Scenarios	1.00	NaN [a]	1.00	1.00
VR Sessions	1.00	NaN [a]	1.00	1.00
Emotional Scenarios ✻ VR Sessions	1.00	NaN [a]	1.00	1.00

[a] The repeated measures has only two levels. The assumption of sphericity is always met when the repeated measures has only two levels

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
R_T1_DIST	0.0620	1	48	0.804
R_T2_DIST	0.1066	1	48	0.745
T_T1_DIST	0.0618	1	48	0.805
T_T2_DIST	2.3076	1	48	0.135



Assumptions Experiment 3: SCENES Distances Travelled Before the logarithmic transformation

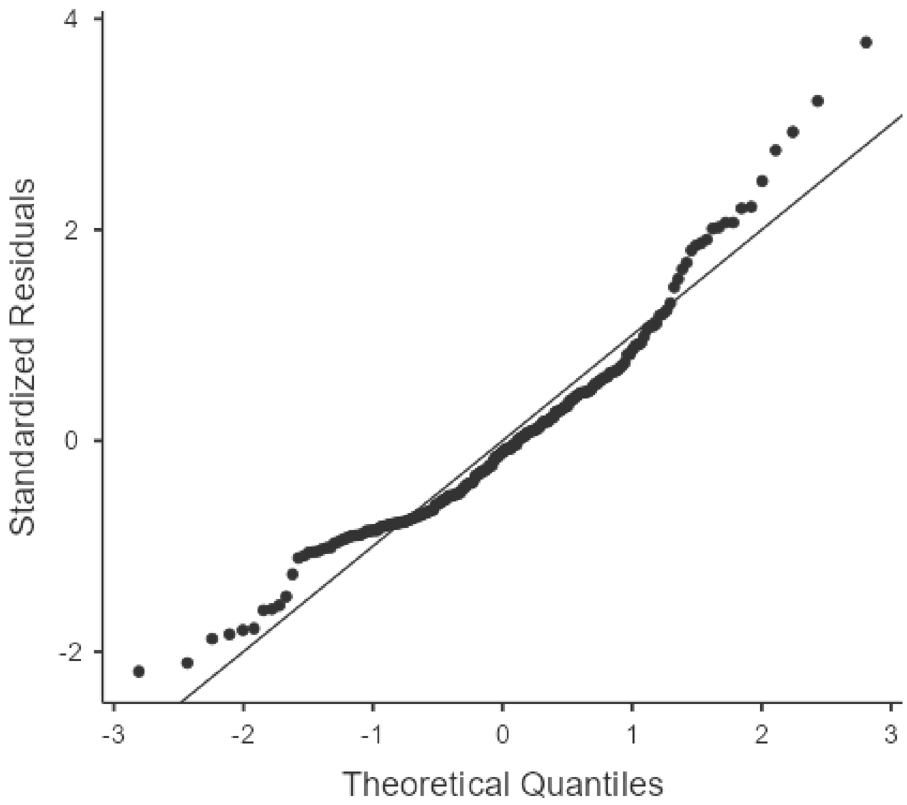
Tests of Sphericity

	Mauchly's W	p	Greenhouse-Geisser ε	Huynh-Feldt ε
Emotional Scenarios	1.00	NaN [a]	1.00	1.00
VR Sessions	1.00	NaN [a]	1.00	1.00
Emotional Scenarios ✻ VR Sessions	1.00	NaN [a]	1.00	1.00

[a] The repeated measures has only two levels. The assumption of sphericity is always met when the repeated measures has only two levels

Homogeneity of Variances Test (Levene's)

	F	df1	df2	p
R_T1_DIST - LOG	1.60788	1	48	0.211
R_T2_DIST - LOG	0.00346	1	48	0.953
T_T1_DIST - LOG	0.91692	1	48	0.343
T_T2_DIST - LOG	1.33804	1	48	0.253



Appendix 6: Experiment 4: Navigational Domains

Table 5.SM4. Mean and SD of objects included in the video recorded for Experiment 4 in Chapter 4. The variables were measured in a pretest on N=22.

Objects	*Pretest Items:*														
	This object is:							*This object makes me feel:*							
	N	Threatening	Reassuring	Negative	Positive	Coherent	Clear	Sad	Neutral	Angry	Disgusted	Surprised	Scarried	Happy	Despised
PC	N=15	1.07(.26)	3.60 (1.88)	1.13 (.51)	4.20 (2.08)	6.67 (.62)	6.93 (.26)	1.00 (.00)	4.07 (2.31)	1.00 (.00)	1.00 (.00)	1.13 (.51)	1.00 (.00)	2.53 (1.88)	1.00 (.00)
Unity Screen	N=15	1.33 (1.29)	3.47 (2.10)	1.27 (.60)	3.80 (1.90)	6.33 (1.35)	6.67 (.62)	1.27 (1.03)	4.73 (2.12)	1.07 (.26)	1.07 (.26)	1.33 (.90)	1.13(.52)	3.07 (2.46)	1.27(1.03)
Surround System	N=16	1.69 (1.40)	2.81 (2.04)	1.69(1.30)	3.63 (2.03)	3.50(2.28)	5.69(1.66)	1.38(.72)	4.06(2.14)	1.06(.25)	1.13(.50)	2.75(2.05)	1.31(.70)	2.88 (2.33)	1.06 (.25)
Pizza	N=17	1.24(.97)	3.53(2.07)	1.18(.39)	5.53(1.74)	4.47(1.94)	6.41(.94)	1.00 (.00)	3.82(2.07)	1.00 (.00)	1.00 (.00)	2.71(1.65)	1.00 (.00)	5.00(1.94)	1.00 (.00)
Record Player	N=18	1.44(1.25)	2.44(1.72)	1.28(1.18)	3.56(2.04)	3.28(2.32)	5.61(2.09)	1.13(.35)	4.40(2.69)	1.13(.35)	1.20(.56)	2.27(1.87)	1.33(1.29)	2.47(1.77)	1.27(1.03)
Snack Machine	N=16	1.19(.54)	3.81(2.32)	1.38(1.02)	4.25(1.88)	5.50(1.97)	6.31(1.01)	1.13(.50)	3.69(2.44)	1.06(.25)	1.00(.00)	1.81(1.33)	1.06(.25)	3.56(2.03)	1.19(.75)
Leaf Painting	N=17	1.65(1.46)	2.76(2.08)	2.18(1.63)	2.82(1.55)	5.00(1.46)	6.06(1.25	2.18(2.04)	4.47(2.32)	1.18(.53)	1.53(1.50)	1.53(.87)	1.65(1.32)	2.00(1.90)	1.29(.99)
Suitcase	N=17	1.18 (.39)	3.35 (2.34)	1.35 (.86)	3.76 (1.89)	4.24(2.02)	6.65 (.49)	1.12 (.49)	4.24 (2.25)	1.06 (.24)	1.06 (.24)	2.56 (1.54)	1.18 (.53)	3.65 (.18)	1.12(.49)
Forest Painting	N=15	1.27 (.60)	4.40 (2.35)	1.33 (.81)	4.47 (1.96)	6.40 (1.06)	1.33 (.82)	3.47 (1.92)	1.07 (.26)	1.00 (.00)	1.87 (1.41)	1.27 (.80)	3.53 (1.88)	1.00 (.00)	4.40(2.35)
Black Chair	N=17	2.65 (1.62)	1.82 (1.70)	3.82(2.35)	1.76 (1.56)	3.82 (2.01)	5.94(1.25)	2.53 (2.12)	3.65 (2.42)	1.5 (1.23)	3.65 (2.26)	2.94 (2.01)	1.94 (1.43)	1.47 (1.46)	2.29(1.96)
First Aid Kit	N=15	1.73 (1.22)	4.20 (2.14)	1.87(1.41)	4.13 (2.00)	4.87 (1.81)	6.27 (.96)	1.53 (1.13)	4.27 (2.34)	1.00 (.00)	1.40 (.91)	1.73 (.96)	1.73(1.33)	1.87 (1.64)	1.13 (.35)
Vacum Cleaner	N=16	1.31(.79)	2.88(2.19)	1.44(.96)	2.88(1.93)	5.50(1.32)	6.69(.60)	1.19(.75)	5.38(1.93)	1.00(.00)	1.19(.75)	1.69(1.35)	1.00(.00)	1.69(1.58)	1.56(1.26)
White Clock	N=17	1.65(1.17)	3.47(2.07)	1.35 (.86)	3.71 (1.93)	5.76 (1.79)	6.18(1.51)	1.24 (.66)	4.53 (2.24)	1.06 (.24)	1.18 (.53)	1.53 (1.18)	1.12 (.33)	1.76 (1.56)	1.18(.52)

Note. * Item responses are measured on a scale from1 (Not at all) to 7 (Very Much).

Table 6.SM4 Means and standard deviations (in parenthesis) of participants Demographics.

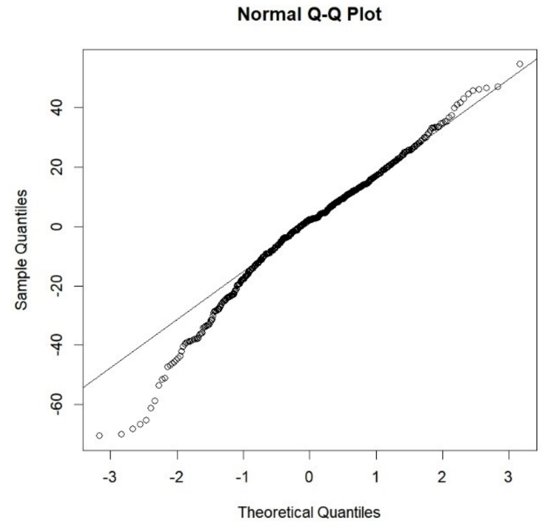
Variables	*Males (N = 243)*	*Females (N = 239)*
Age	27.27 (7.55)	28.26 (8.85)
Live Area		
Rural Area	21	22
Town	65	71
City	126	121
Metropolis	27	29
Amount of GPS Daily Use (1 = Not at all; 5 = Always)	3.14 (1.00)	3.52 (1.01)
Do you work in an Office?		
Yes	87	99
No	152	144
Wayfinding Questionnaire Total Score	92.92 (15.94)	89.42 (15.84)
Navigation and Orientation 11 items (1 = Not Applicable; 7 = Fully Applicable)	51.02 (12.91)	42.36 (12.79)
Spatial Anxiety 3 items (1 = Not Applicable; 7 = Fully Applicable)	30.22 (10.46)	38.43 (9.75)
Distance Estimation 8 items (1 = Not Applicable; 7 = Fully Applicable)	11.68 (4.11)	8.63 (3.95)

Appendix 7: Experiment 5: VSWM

CBT pre outlier removal

QQplot for the test of normality of residuals. There is a marked violation of normality of residuals.

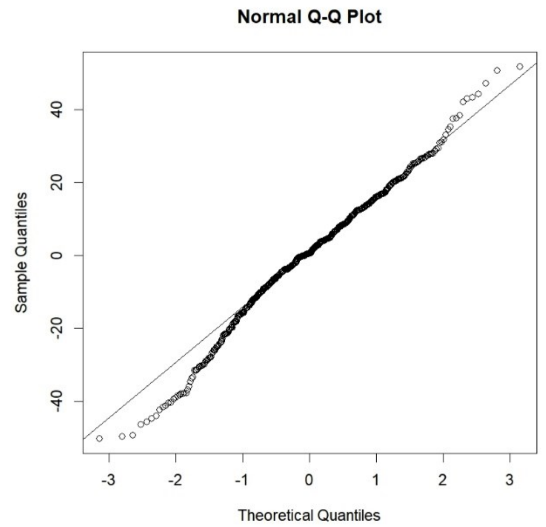
Leven's test of homogeneity of variance. It has to be run on each of the repeated measures, Time 1 and Time 2. Time 1: $F(5, 318) = .87$, $p = .50$. Time 2: $F(5, 318) = .71$, $p = .62$. There is no violation.



CBT after outlier removal

QQplot for the test of normality of residuals. The violation of normality is less marked.

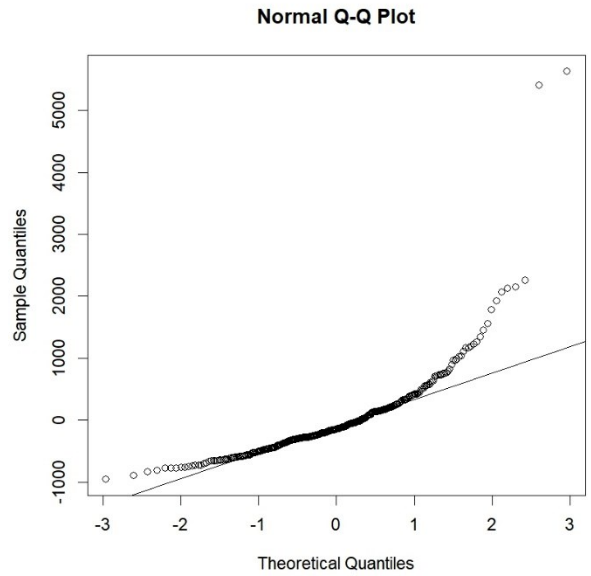
Leven's test of homogeneity of variance. It has to be run on each of the repeated measures, Time 1 and Time 2. Time 1: $F(5, 296) = .75$, $p = .60$. Time 2: $F(5, 296) = 1.77$, $p = .12$. There is no violation.



DNMS RT pre outlier removal

QQplot for the test of normality of residuals. There is a marked violation of normality of residuals.

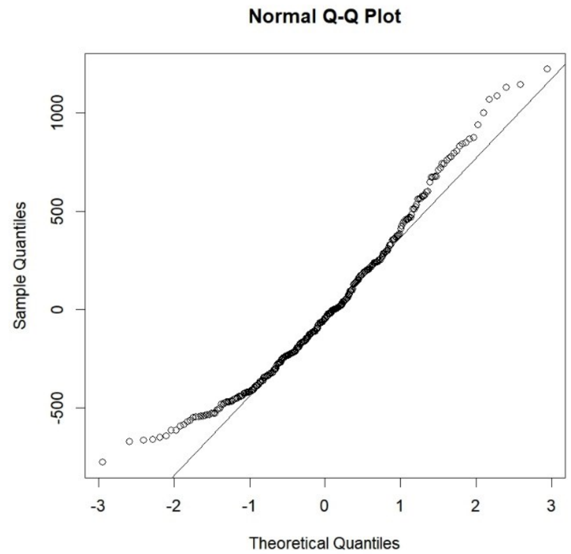
Leven's test of homogeneity of variance: $F(5, 318) = 1.34$, $p = .24$.



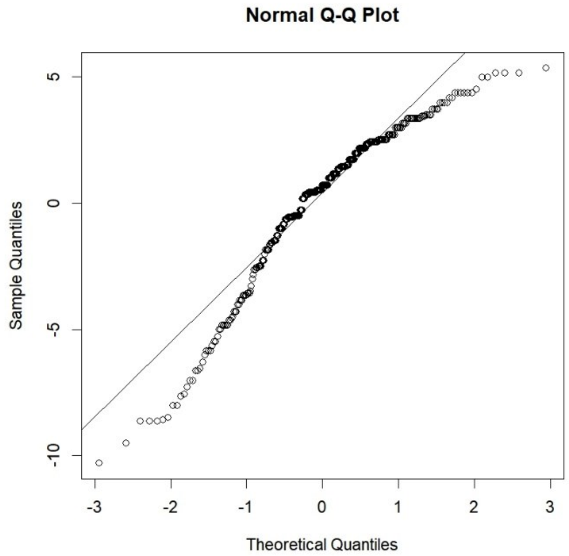
DNMS RT after outlier removal

QQplot for the test of normality of residuals. The violation of normality is less marked.

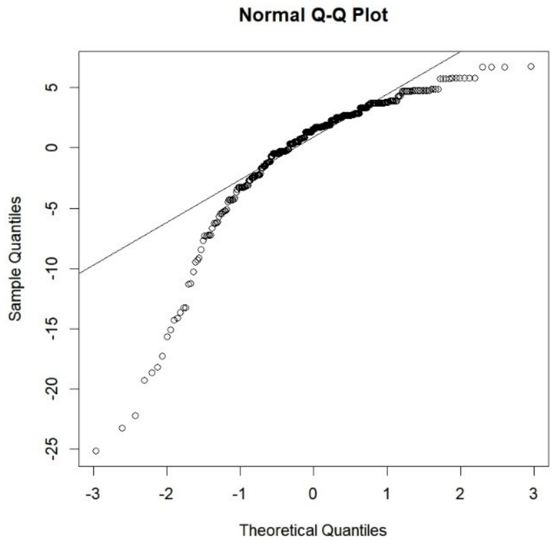
Leven's test of homogeneity of variance: $F(5, 302) = .73$, $p = .60$. There is no violation.



DNMS Scores pre outlier removal



QQplot for the test of normality of residuals. The assumption is markedly violated.
Leven's test of homogeneity of variance: $F(5, 318) = 2.22$, $p = .05$. There is a slight violation.



DNMS Scores after outlies removal.
Outlier removal was not improving much the violation of the assumption of normality and was increasing the violation of homogeneity of variance. Thus, we used an ANOVA technique which is more robust to such violations.

QQplot for the test of normality of residuals. The distribution is improved but still evidently violating the assumption.
Leven's test of homogeneity of variance: $F(5, 300) = 2.59$, $p = .02$. There is a significant violation.

Table 4.1 Means and standard deviations (in parenthesis) and median and interquartile range (in parenthesis) of Corsi Block Task (CBT) expressed in percentages of success at T1 and T2 and DNMS RT and Scores as a function of gender and emotional condition. Outliers were not removed.

	Gender	Emotons	SCORE_DNMS/42	RT_DNMS	CBT-T1	CBT-T2	CBT-T1-T2	AGE
N	Male	Neutral	54	54	54	54	54	54
		Fear	58	58	58	58	58	58
		Anger	59	59	59	59	59	59
	Female	Neutral	45	45	45	45	45	45
		Fear	57	57	57	57	57	57
		Anger	51	51	51	51	51	51
Mean	Male	Neutral	37.5	1408	50.7	54.6	-3.91	39.6
		Fear	35.3	1587	52.9	41.3	11.6	39.5
		Anger	37.7	1288	46.1	50.1	-3.98	38.2
	Female	Neutral	36.3	1495	50.0	53.3	-3.29	38.0
		Fear	35.3	1400	45.6	51.8	-6.28	40.0
		Anger	37.2	1264	47.1	48.2	-1.10	39.3
Median	Male	Neutral	38.0	1264	54.0	54.0	0.00	39.0
		Fear	37.0	1321	54.0	48.0	6.00	39.5
		Anger	39.0	1167	48	51	0	40.0
	Female	Neutral	38.0	1326	54	54	0	37.0
		Fear	37.0	1354	54	54	0	42.0
		Anger	39.0	1143	54	54	0	38.0
Standard deviation	Male	Neutral	2.89	585	18.4	19.7	22.4	10.3
		Fear	6.52	1206	18.3	20.2	25.5	11.0
		Anger	4.57	482	23.4	19.8	21.4	11.7
	Female	Neutral	4.93	592	19.8	13.4	21.7	10.5
		Fear	5.51	524	20.9	16.5	21.2	10.8
		Anger	5.62	446	20.3	18.9	23.7	11.6
IQR	Male	Neutral	3.75	582	15.0	25.0	26.0	17.0
		Fear	7.00	609	12.0	19.0	35.0	17.8
		Anger	3.00	430	25.0	15.0	21.5	18.0
	Female	Neutral	6.00	661	18.0	12.0	19.0	18.0
		Fear	6.00	523	14.0	18.0	22.0	16.0
		Anger	4.00	581	20.0	20.0	27.5	18.5