Journal of Environmental Psychology 88 (2023) 102032

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

Environmental cognitive load and spatial anxiety: What matters in navigation?

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ARTICLE INFO

Handling Editor: Giulia D'Aurizio

Keywords:
Spatial anxiety
State-Trait Anxiety
Cognitive load
Human navigation
Virtual reality
Egocentric references
Allocentric references

ABSTRACT

Spatial navigation is essential for orienting oneself in familiar and novel environments. Several internal factors may affect spatial navigation, such as anxiety. This study explored the mediating role of anxiety (spatial, trait and state) in the relationship between cognitive load and spatial navigation (egocentric and allocentric) using parallel mediation models. A sample of 125 participants (60 females) completed self-reported measures of anxiety (spatial and state-trait) during free navigation in a virtual reality square with or without environmental cognitive load. After the virtual learning experience, three spatial tasks evaluating landmark recognition and the use of egocentric and allocentric coordinates were administered. Results showed that spatial anxiety partially mediated the relationship between environmental load and spatial skills, specifically for egocentric and allocentric tasks. In addition, trait anxiety mediated the relationship between environmental load and allocentric performance. Overall, these findings update the Environmental Knowledge Model (EKM) that explains human navigation in terms of individual and environmental factors. The study results suggest that navigation could be facilitated by reducing anxiety and the spatial complexity of the environment.

1. Introduction

Spatial navigation is critical for survival from an evolutionary perspective as it plays a crucial role in most everyday life activities. Spatial navigation is vital for orienting oneself in familiar and novel environments. Without navigational skills, finding a route, returning to a specific place, locating objects, or even moving freely in physical space would be impossible. Spatial navigation allows us to estimate our position and remember, plan for, and mentally representing the spatial relationships between objects (see Bocchi, Palmiero, Persichetti, et al., 2022; Bocchi, Palmiero, & Piccardi, 2022; Montello, 1998; Piccardi, Bocchi, Palmiero, Verde, & Nori, 2017). Spatial navigation is anchored by spatial information and the objects or landmarks surrounding us (e.g., Palmiero & Piccardi, 2017; Piccardi, Guariglia, Nori, & Palmiero, 2020). Spatial and object information is integrated at the neural level, specifically by the ventral visual pathway and associated perirhinal and lateral entorhinal cortices, allowing encoding of the spatial relationships between different objects and between objects and the self (Connor & Knierim, 2017).

When spatial knowledge is encoded and stored in memory, two different reference frames are used: egocentric or body-centred reference frames, in which spatial information and objects are represented with respect to the individual (e.g., self–object—the door is 1 m away from me); and allocentric or world-centred reference frames, in which spatial information and objects are represented with respect to the environment, independently of the individual's position (e.g., object–object—the fountain is north of the skyscraper) (Burgess, 2006). Thus, whereas egocentric reference frames play a key role in controlling movements in the near peripersonal space (e.g., arm reaching space), allocentric reference frames support object and scene recognition, and the planning of future movements in the far extrapersonal space (e.g., spaces outside of arm's reach) (Berti, Smania, & Allport, 2001; Kosslyn,

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https://doi.org/10.1016/j.jenvp.2023.102032
Received 21 December 2022; Received in revised form 27 February 2023; Accepted 27 February 2023
Available online 22 May 2023
0272-4944/

1994). These reference frames are involved in reaching a goal during navigation, which requires determining the location of the self and estimating the target destination, selecting and monitoring the route from the starting point to the target destination, and recognizing the target destination (Lawton & Kallai, 2002; Nori, Grandicelli, & Giusberti, 2009). Egocentric and allocentric frames of reference are needed to specify nonmetric (categorical) and metric (coordinate) spatial encodings, which are two different but complementary aspects of spatial cognition (Lopez & Bosco, 2022; Lopez, Caffò, & Bosco, 2021; Lopez, Caffò, Postma, & Bosco, 2020; Lopez, Postma, & Bosco, 2020). Indeed, categorical spatial encoding refers to the relative positions of landmarks in the environment, and people usually use spatial encoding to describe a path or to memorize landmark locations (e.g., in front of, right, and left), whereas coordinate spatial encoding refers to metric distances between landmarks (the fountain is 300 m from the church and farther away from the city hall) (e.g., Lopez, Caffò, Spano, & Bosco, 2019). Although one might assume that egocentric and allocentric processes function automatically in encoding and retrieving spatial information (e.g., Ellis, 1990; Pouliot & Gagnon, 2005) as they are crucial for survival, allocentric processing is not supported by automatic processes (e.g., Köhler, Moscovitch, & Melo, 2001; Naveh-Benjamin, 1988), whereas egocentric processing is more automatic (e.g., Ellis, 1990; Pouliot & Gagnon, 2005). In general, allocentric processing requires more cognitive resources because it requires detachment from egocentric processing (Ruggiero, Iachini, Ruotolo, & Senese, 2009): the targets are out of the sensory field, and the integration of information, self-monitoring and planning of paths are more elaborated (Wolbers & Wiener, 2014). In particular, the environment-based allocentric frame requires cognitive resources, as it relies on the formation of stable cognitive maps of the environment (Iaria, Palermo, Committeri, & Barton, 2009; Montefinese, Sulpizio, Galati, & Committeri, 2015). Consequently, the presence of a cognitive load during spatial navigation, especially when individuals are processing both allocentric and egocentric coordinates, is unquestionable. Specifically, cognitive load refers to 'the level of mental energy required to process a given amount of information' (Cooper, 1990, p. 108) and the level of working memory resources required (Sweller, 1988). Cognitive load theory (CLT) (Sweller, 1988, 2010) describes three types of cognitive load: a) intrinsic cognitive load, which reflects the complexity of information to be processed, defined by the number and interactivity of elements that must be learned, and relies on the learner's level of expertise; b) extraneous cognitive load, which relies on the presentation of instructions; and c) germane cognitive load, which reflects the mental resources used to process schemata in long-term memory and also depends on the learner's characteristics.

Thus, the present study first explored the extent to which intrinsic cognitive load affects egocentric or allocentric judgements in a virtual reality (VR) environment. Several studies have demonstrated the importance of cognitive load in spatial learning. However, most studies concern the spatial intrinsic cognitive load in a static context (i.e., in front of a computer; Deyzac, Logie, & Denis, 2006; Knight & Tlauka, 2016), and are not representative of our everyday life activities, such as learning and moving through an environment. To the best of our knowledge, only two studies have attempted to study travellers' cognitive load. The first revealed that occasional travellers showed higher cognitive load responses than regular travellers in both environmental conditions (Armougum, Orriols, Gaston-Bellegarde, Joie-La Marle, & Piolino, 2019). The second demonstrated the influence of higher cognitive load on the ability to perform a navigation task by analysing differences in EEG neural responses. The EEG results showed that the frontal midline region exhibited a specific higher power in the low-frequency band in the high workload condition that required performing a navigation task after the additional cognitive burden was imposed (Do, Singh, Cortes, & Lin, 2020).

Notably, the extent to which the intrinsic cognitive load in the navigational tasks is affected by intervening variables must also be explored. Several internal factors may affect spatial navigation; above all, learning and the delayed recall of spatial information, such as familiarity with the environment, personality traits, cognitive styles, gender, and age (e.g., Lawton, 1996; Nori, Grandicelli, & Giusberti, 2009). One of the possible mediating factors is anxiety, which is the focus of the present study. Anxiety is a discrete emotional state triggered by novel, adverse and threatening situations that may have a potential negative outcome (Brooks & Schweitzer, 2011). Anxiety is characterized by negative emotions (worry or apprehension), high activity (physiological arousal) (Russell, 1980) low certainty and low control (Smith & Ellsworth, 1985). Anxiety can be defined as a state or a trait, with the former reflecting a more transient reaction to an adverse situation and the latter describing a consistent tendency to feel negative emotions across different situations (Barlow, 2002; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983).

Spatial anxiety is particularly important for navigation and reflects feelings of apprehension and fear regarding navigating an environment, orienting oneself, and performing spatial tasks (Bryant, 1982; Kozlowski & Bryant, 1977; Lawton, 1994; Montello, Lovelace, Golledge, & Self, 1999).

Spatial anxiety has been shown to negatively affect navigation (e.g., Hund & Minarik, 2006; Pazzaglia, Meneghetti, & Ronconi, 2018), with women reporting more spatial anxiety and general anxiety than men in the context of environmental navigation (see Lawton, 1994). Thus, it is unsurprising that navigation based on allocentric processing generates more spatial anxiety, as it is more cognitively demanding than navigation based on egocentric processing (Alvarez-Vargas, Abad, & Pruden, 2020). In particular, spatial anxiety was negatively correlated with navigational strategies using survey or orientation representations (Lawton, 1994, 1996), which are supported by allocentric processes. Schmitz (1997) also showed that males are characterized by lower levels of spatial anxiety than females and prefer to include more directional elements in verbal descriptions of a maze. Thus, individuals with high levels of spatial anxiety do not use allocentric processes and tend to become lost and confused more easily. Similarly, Lawton and Kallai (2002) showed that men reported using mostly orientation strategies (e.g., keeping track of the direction using the cardinal points, north, south, east, or west), whereas women used mostly route strategies, which are more ego-centred (e.g., asking for directions and information about turns at specific landmarks) and are also characterized by higher spatial anxiety. Furthermore, people with spatial anxiety use GPS less than others during navigation; their behaviour was found to partially mediate the relationship between anxiety and self-reported navigation ability (He & Hegarty, 2020). However, it is important to highlight that the aforementioned studies failed to find a significant relationship between spatial anxiety and navigation (e.g., Prestopnik & Roskos-Ewoldsen, 2000; Saucier et al., 2002). In addition, the direction of causality between spatial anxiety and navigation remains unclear, given that being aware of one's inability to navigate can generate spatial anxiety (Weisberg & Newcombe, 2018). Interestingly, whereas trait anxiety was found to interact only with low mental rotation ability, yielding a disadvantage in a map-based route learning task (Thoresen et al., 2016), general anxiety did not appear to affect navigation (Walkowiak, Foulsham, & Eardley, 2015). Therefore, people with high trait anxiety scores do not necessarily have high spatial anxiety scores; thus, it is important to separately manage the two domains (Walkowiak et al., 2015). In contrast, state anxiety affects one's ability to acquire and represent spatial information, particularly among women. People with this characteristic rely on approximate information, such as landmarks and familiar routes, without capturing additional environmental details (Castelli, Corazzini, & Geminiani, 2008; Nori, Mercuri, et al., 2009). However, the results of a recent study by Walkowiak et al. (2015) suggested that neither state nor trait anxiety correlates with navigational performance.

Overall, these findings show that the relationships between anxiety and navigation, as defined regarding egocentric and allocentric processes, need to be further explored. Furthermore, some studies have suggested that VR graphical factors might interfere with the level of mental effort required for exploring and learning about irrelevant elements in the VR environment (Huang, 2011; Zucchelli, Piccardi, & Nori, 2021), increasing the intrinsic cognitive load. Zucchelli et al. (2021) found that people with agoraphobia showed lower performance than those without in solving spatial tasks in a VR environment with phobic stimuli. This result supports the hypothesis that anxiety could mediate the relationship between virtual navigation cognitive load and spatial performance. On the basis of these results, our study explored cognitive load-navigation and the mediating role of anxiety (spatial, trait and state) using a parallel mediation model on navigation. In particular, navigation ability was assessed regarding landmark recognition and egocentric and allocentric judgement processes by using VR. Specifically, we hypothesized that the relationship between a high virtual cognitive load and navigational performance errors in landmark recognition egocentric and allocentric tasks is partially mediated by spatial anxiety.

2. Method

2.1. Participants

To establish the minimum sample size necessary to perform the mediation analyses among our variables of interest, a power analysis was conducted using GPower 3.1. software (Faul, Erdfelder, Lang, & Buchner, 2007). Considering nine predictors (spatial, trait and state anxiety, cognitive load, age, education, gender, rate of computer use, prior use of video games) for our dependent variables, a medium effect size $f2 = 0.15$, $\alpha = 0.05$ and power = .80 (considered an acceptable effect size, Cohen, 1988), the minimum total sample size was 114 participants. We recruited 125 participants from the university campus through advertisements on social networks and bulletin boards (60 females; age M = 26.31, SD = 4.01 years old; education M = 15.11, SD = 2.36 years). The exclusion criteria were the presence of mental disorders, general medical conditions or drug abuse (APA, 2013), and none of the participants were excluded. Moreover, given the use of virtual reality equipment for the experiment, computer use ($t_{123} = -0.69$, $p = .24$) and prior use of video games ($X^2_{123} = 0.34$, $p = .56$) between the two experimental conditions (high and low cognitive load) were assessed, and no differences were found. Informed consent was obtained from all participants.

2.2. Anxiety assessment and experimental conditions

2.2.1. Spatial anxiety scale

The Spatial Anxiety Scale (SAS; Lawton, 1994) was used to measure the level of anxiety experienced in daily life situations requiring spatial or navigational abilities (e.g., Trying a new route that you think will be a shortcut without the benefit of a map; finding your way to an appointment in an area of a city that you are not familiar with, or finding your way out of a complex arrangement of offices that you have visited for the first time). The SAS comprises 8 items. Participants were asked to rate their level of anxiety on a 5-point scale (from 1 = Not at all to 5 = Very Much), where the higher scores corresponded to higher spatial anxiety levels. Cronbach's alpha for the present sample was 0.88.

2.2.2. Trait and state anxiety questionnaire

The State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983) was used to measure state and trait anxiety, distinguishing between temporary anxiety related to the circumstances and general, stable anxiety linked to individual characteristics. The inventory comprises 40 self-reported items, 20 per dimension. The participants indicated their agreement with these statements on a 4-point scale (from 1 = Not at all to 4 = Very Much). The Trait subscale (STAI-T) comprised seven statements about the absence of anxiety and 13 statements about anxious one generally feels on a daily basis. Similarly, the State subscale (STAI-S) comprised ten statements about the absence of anxiety and 10 statements about how anxious the participant felt in the moment. In previous studies, internal consistency coefficients for the scale ranged from 0.86 to 0.95; test-retest reliability coefficients ranged from 0.65 to 0.75 over a 2-month interval. Cronbach's alpha for the present sample was 0.85.

2.2.3. Virtual reality environment

A VR multimodal environment was designed in the Space and Virtual Reality laboratory to simulate an everyday life scenario at a public square. The square was 115 × 60 m in size, corresponding to a famous Italian square (Piazza Maggiore in Bologna; Zucchelli et al., 2021), in which several buildings and shops were located, a newsstand, a fountain, the town hall, the public library, a florist, a museum, a theatre, a smoke shop, a pharmacy, a bank, a jewellery store, a church, and two cafes (one with outdoors and the other without), based on consistent with the observations made in different squares in Italian cities. To create a VR as close as possible to a real-life environment, immersion, interaction, and interface were considered (Fuchs & Moreau, 2006). The immersive level of the virtual square was obtained by using a VR helmet (Windows Mixed Reality Headset Controller–Gyro Sensor–HDMI 2.0-USB 3.0, resolution 2.880 × 1.440 pixels, FOV 100°). The interactive aspect depends on the ability to move freely in the virtual environment in order to acquire subject-to-object relationships and object-to-object relationships. The participants moved through the environment using a wireless controller. The interface used was easily understood and ergonomic (Fuchs, Moreau, & Guitton, 2011). To reduce or eliminate the presence of cybersickness symptoms (i.e., nausea and headache), participants explored a training environment (the living room of an apartment) to optimize, as much as possible, the process of navigating with the VR headset. No participant experienced cybersickness symptoms. Two versions of the same environment were developed to investigate the influence of cognitive load on anxiety traits: in the first, participants were exposed to the public square with buildings alone (low load condition); in the second, participants were exposed to the public square with buildings plus a crowd (approximately 80 people) standing along the entire perimeter (high load condition with irrelevant cues) (Fig. 1).

2.2.4. Behavioural measure of cognitive load

2.2.4.1. Landmark recognition task (Zucchelli et al., 2021). Participants were asked to recognize 10 out of 20 landmarks (10 targets and 10 fillers). The fillers represented 3D buildings semantically congruent with a public square. The score ranged from 0 to 10 (if the participant correctly identified all the targets and ignored the fillers) (Fig. 1).

2.2.4.2. The egocentric judgement task (Zucchelli et al., 2021) measured the use of egocentric coordinates, that is, the understanding of the relationship between buildings and the participant's position. The participant was asked to imagine being in a specific position within the virtual square and indicate which building was located on his or her right/left/in front/behind him or her (e.g., "You are coming out of the newsstand, what is on your left?" The right answer is "The fountain": Fig. 1). The task included 10 questions (accuracy ranged from 0 to 10).

2.2.4.3. The allocentric judgement task (Zucchelli et al., 2021) measured the use of allocentric coordinates, that is, the understanding of the relationship of the buildings located in the square, regardless of the participant's location. The participant was asked to imagine being at a specific point within the square, looking towards a building he or she was asked to indicate the position of and identify the location of another building, with respect to the first one, using a circular dial. The task required making 10 directional judgements; half were aligned (the imagined perspective was the same as the learned one during the navigation), and half were contra-aligned (the imagined perspective was rotated by 180° from the learned one during the navigation). For example, "You are at the library, and you are looking towards the bank, please indicate where the library is with respect to the bank" (Fig. 1). Participants used a circumference depicted on paper to perform the directional judgement, similar to the procedure used by Kozhevnikov

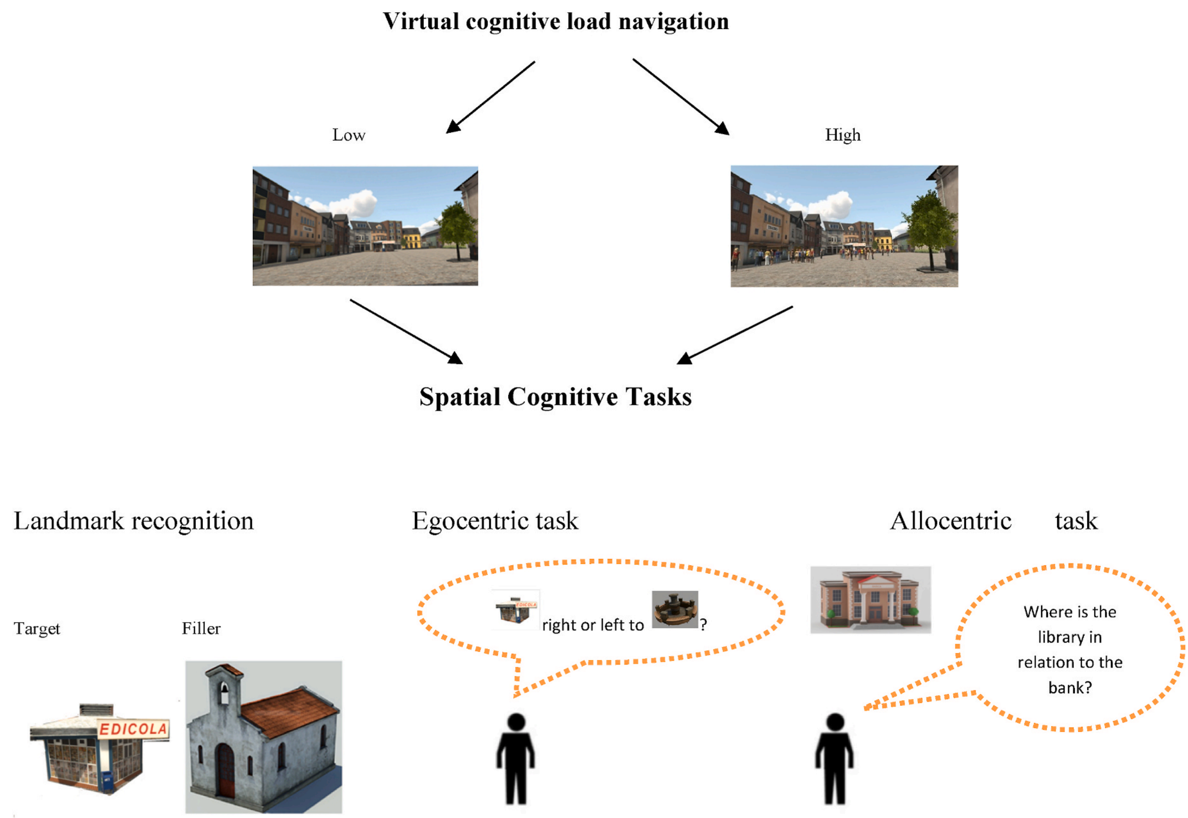

Fig. 1. Virtual cognitive load navigation and spatial cognitive tasks.

and Hegarty (2001). On this circumference, a mark indicated 0°, which was the position of the first building (bank) the participant was asked to imagine looking towards. Successively, the participant was asked to place another mark on the circumference indicating the target position of the second building (library). The absolute angular error, i.e., difference in degrees between the right position of the target and the position marked by the participant, was measured. In total, 10 directional judgements were made: 5 aligned and 5 contra-aligned. Therefore, two means of angular errors were calculated, one for the aligned judgement and one for the contra-aligned judgement.

2.3. Procedure

All participants signed an informed consent form informing that they would be navigating through a virtual square and solving a series of spatial tasks. Then, they were asked to provide some demographic information (age, gender, education, habitual use of computer, and medical information to exclude the presence of mental disorders, general medical conditions or drug abuse). Then, the participants completed screening questionnaires for anxiety (STAI and SAS) through the software Qualtrics (First release: 2005, Provo, Utah, USA, Available at: https://www.qualtrics.com) either before or after navigating in VR and performing the spatial tasks. The experiment was conducted after the participants familiarized themselves with the VR equipment. The participants were required to navigate the virtual square for 12 min, the time necessary to acquire information about the different landmarks and the relationships among them (Zucchelli et al., 2021). The participants were instructed to navigate freely in any direction with no tasks except for paying attention to the surrounding environment to obtain information required for the subsequent spatial tasks. After the virtual learning experience, the three spatial tasks, were administered in a randomized order. The experimental procedure lasted approximately 45 min.

2.4. Data analysis

The data were analysed using SPSS 26.0. A series of parallel mediation analyses were performed using Hayes' PROCESS macro for SPSS (Hayes, 2022) to evaluate whether measures of anxiety (spatial, trait and state) could mediate the relationship between cognitive load (low/high) and performance in spatial tasks (landmark recognition, egocentric and allocentric judgement scores). The significance threshold was $p < .05$. The dataset is available at the following link: https://osf.io/9xf38/?view_only=95dec97101cf4e1ba1a030c2009d7823.

3. Results

3.1. Demographics

We performed a series of regression analyses to assess the relationships between demographic variables (age, gender, education, frequency of pc use) and the dependent variables (landmark score, egocentric judgements, aligned and contro-aligned allocentric judgements). We classified gender coding men as −1 and women as 1, as suggested by Howitt and Cramer (2011). Regarding the landmark score ($F_{4,124} = 0.34$, $p = .84$) no predictions by age ($p = .48$), gender ($p = .85$), frequency of computer use ($p = .32$), and education ($p = .79$) were revealed; regarding egocentric judgements ($F_{4,12\ 4} = 2.24$, $p = .07$) no predictions by age ($p = .85$), gender ($p = .007$), frequency of computer use ($p = .61$), and education ($p = .14$) were present. Regarding aligned allocentric judgements ($F_{4,124} = 3.48$, $p < .05$) no prediction by age ($p = .12$), frequency of computer use ($p = .97$), and education ($p = .63$) were revealed, whereas gender predicted performance ($\beta = 0.28$, $p < .05$). The findings were the same regarding contra-aligned allocentric judgements ($F_{4,124} = 2.39$, $p = .05$), with no prediction by age ($p = .39$), frequency of computer use ($p = .79$), and education ($p = .30$) but a predictive effect of gender on performance ($\beta = 0.22$, $p < .05$) (higher scores corresponded to higher angular error estimation): females showed lower scores. Thus, gender was included as a covariate in the mediation analyses based on allocentric judgement tasks.

The correlations among the variables are shown in Table 1.

3.2. Parallel mediation analysis of anxiety in the relationship between cognitive load and landmark task performance

The mediation analysis considering the relationship between the experimental load condition and the landmark task was not performed since the cognitive load was not predictive of the performance in the landmark task ($\beta = -.12$, $p = .46$). For the sake of clarity, we specify that the three variables of anxiety considered do not predict performance in the landmark task (spatial anxiety $p = .45$; state anxiety $p = .31$, and trait anxiety $p = .87$).

3.3. Parallel mediation analysis of anxiety in the relationship between cognitive load and egocentric judgement task

The mediation analysis considered the relationship between the experimental cognitive load (low/high) and egocentric task performed by the participants and the three measures of anxiety collected (spatial, trait and state anxiety) as mediators. The experimental load condition positively predicted the three measures of anxiety: the higher the former was, the higher the latter was (spatial anxiety $\beta = 1.81$, $p < .001$; state anxiety $\beta = 2.60$, $p < .05$ and trait anxiety $\beta = 2.56$, $p < .05$). Among the three measures of anxiety, spatial anxiety negatively predicted performance on the egocentric task ($\beta = -0.13$, $p < .05$), whereas trait anxiety ($\beta = -0.01$, $p = .62$) and state anxiety ($\beta = -0.02$, $p = .26$) did not. The mediation analysis showed that spatial anxiety mediated the relationship between cognitive load and the egocentric task (Effect = −.24; BootLLCI - BootULCI = −0.4361; -0.0785), whereas trait anxiety (Effect = −0.03, BootLLCI – BootULCI = −0.2306; 0.1162) and state anxiety (Effect = −0.06, BootLLCI - BootULCI = −0.2049; 0.0468) did not. The direct relationship between cognitive load and the egocentric task was still significant ($\beta = -.71$, $p < .05$): the higher the former was, the lower the latter was; thus, the mediation was partial (see Fig. 2).

3.4. Parallel mediation analysis of anxiety in the relationship between cognitive load and aligned allocentric judgements, with gender as a covariate

The mediation analysis considered the relationship between the experimental cognitive load (low/high) and aligned allocentric judgement task performed by the participants and the three measures of anxiety (spatial, trait and state anxiety) as mediators, with gender as a covariate. The analysis showed that the experimental load condition positively predicted the three measures of anxiety: the higher the first was, the higher the latter was (spatial anxiety $\beta = 1.72$, $p < .001$; state anxiety $\beta = 2.52$, $p < .05$ and trait anxiety $\beta = 2.52$, $p < .05$). Among the three measures of anxiety, spatial anxiety ($\beta = 4.11$, $p < .001$) and trait anxiety ($\beta = 1.61$, $p < .05$) positively predicted the angular error performed in the aligned allocentric judgement task, whereas state anxiety ($\beta = 0.26$, $p = .66$) did not. The mediation analysis showed that spatial anxiety mediated the relationship between cognitive load and the aligned allocentric judgement task (Effect = 7.09; BootLLCI - BootULCI = 2.2930; 12.8291), whereas trait anxiety (Effect = 4.07, BootLLCI - BootULCI = −0.2283; 10.0533) and state anxiety (Effect = 0.66, BootLLCI - BootULCI = −2.1193; 3.9196) did not. The direct relationship between cognitive load and the aligned allocentric judgement task was still significant: the higher the first was, the higher the angular error in the aligned allocentric judgement task was ($\beta = 19.39$, $p < .05$); thus, the mediation was partial (see Fig. 3).

3.5. Parallel mediation analysis of anxiety in the relationship between cognitive load and contra-aligned allocentric judgements, with gender as a covariate

The mediation analysis considered the relationship between the cognitive load (low/high) and contra-aligned allocentric judgements performed and the three measures of anxiety (spatial, trait and state anxiety) as mediators, with gender as a covariate. The load condition positively predicted the three measures of anxiety: the higher the former was, the higher the latter was (spatial anxiety $\beta = 1.72$, $p < .001$; state anxiety $\beta = 2.52$, $p < .05$ and trait anxiety $\beta = 2.52$, $p < .05$). Among the three measures of anxiety, spatial anxiety ($\beta = 4.84$, $p < .001$) and trait anxiety ($\beta = 2.46$, $p < .05$) positively predicted the angular error performed in the contra-aligned allocentric judgements, whereas state anxiety ($\beta = -0.14$, $p = .83$) did not. The mediation analysis showed that spatial anxiety (Effect = 8.34; BootLLCI - BootULCI = 3.0193–14.3373) and trait anxiety (Effect = 6.22; BootLLCI - BootULCI = 1.4476; 12.6186) mediated the relationship between cognitive load and the contra-aligned allocentric judgements, whereas state anxiety (Effect = −.36, BootLLCI - BootULCI = −4.1798; –3.1653) did not. The direct relationship between cognitive load and the contra-aligned allocentric judgements was still significant: the higher the first was, the higher the angular error in aligned allocentric judgements was ($\beta = 18.49$, $p < .05$); thus, the two mediations were partial (see Fig. 4).

4. Discussion

The main aim was to better understand the extent to which environmental cognitive load influences navigation ability considering the mediating role of anxiety (state, trait and spatial anxiety). The relationship between spatial anxiety and navigation is well known (e.g., Lawton, 1994), but to our knowledge, whether spatial anxiety can mediate the relationship between environmental complexity and spatial

Table 1
Means, standard deviations and intercorrelations of demographic variables (age, gender, education, frequency of pc use) and the dependent variables (landmark score, egocentric judgements, aligned and contro-aligned allocentric judgements).

	Mean (SD)	Intercorrelations										
		1	2	3	4	5	6	7	8	9	10	**11**
1. Age	26.31(4.01)	–	.02	.00	.08	−.03	.04	−.03	−.05	−.02	−.12	−.07
2. Gender	60 F; 65 M	.02	–	.16	−.11	.38**	.17	.09	.00	−.22*	.29**	.24**
3. Education	15.11(2.36)	.00	.16	–	−.12	−.03	.16	.18*	.01	.09	.08	.13
4. Frequency of pc use	1.62(0.94)	.08	−.11	−.12	–	.12	.10	.11	.08	−.03	−.04	−.06
5. Spatial anxiety	17.42(5.81)	−.03	.38**	−.03	.12	–	.20*	.42**	−.08	−.42**	.53**	.53**
6. State anxiety	29.38(10.97)	.04	.17	.16	.10	.20*	–	.54**	.06	−.25**	.29**	.25**
7. Trait anxiety	38.42(9.29)	−.03	.09	.18*	.11	.42**	.54**	–	−.00	−.30**	.43**	.45**
8. Landmark score	14.62(1.88)	−.05	.00	.01	.08	−.08	.06	−.00	–	−.04	−.06	−.16
9. Egocentric judgements	4.46(2.64)	−.02	−.22*	.09	−.03	−.42**	−.25**	−.30**	−.04	–	−.45**	−.40**
10. Aligned allocentric judgements	106.48(76.98)	−.12	.29**	.08	−.04	.53**	.29**	.43**	−.06	−.45**	–	.73**
11. Contra-aligned allocentric judgements	129.07(87.39)	−.07	.24**	.13	−.06	.53**	.25**	.45**	−.16	−.40**	.73**	-

$*p < .05$: $**p < .001$.

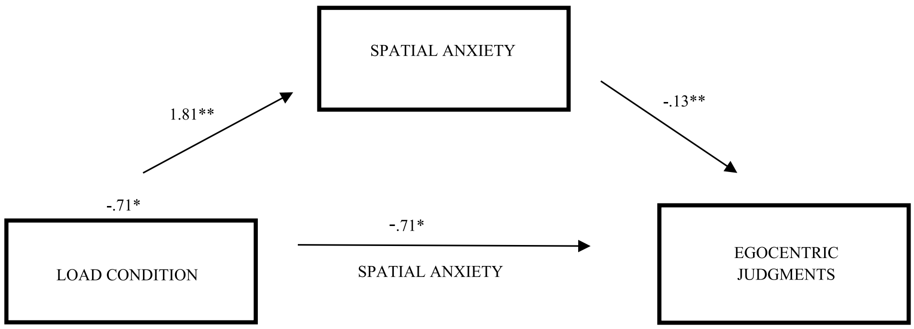

Fig. 2. Mediation graph analysis considering cognitive load as a predictor, anxiety as a mediator and egocentric judgement as the dependent variable.

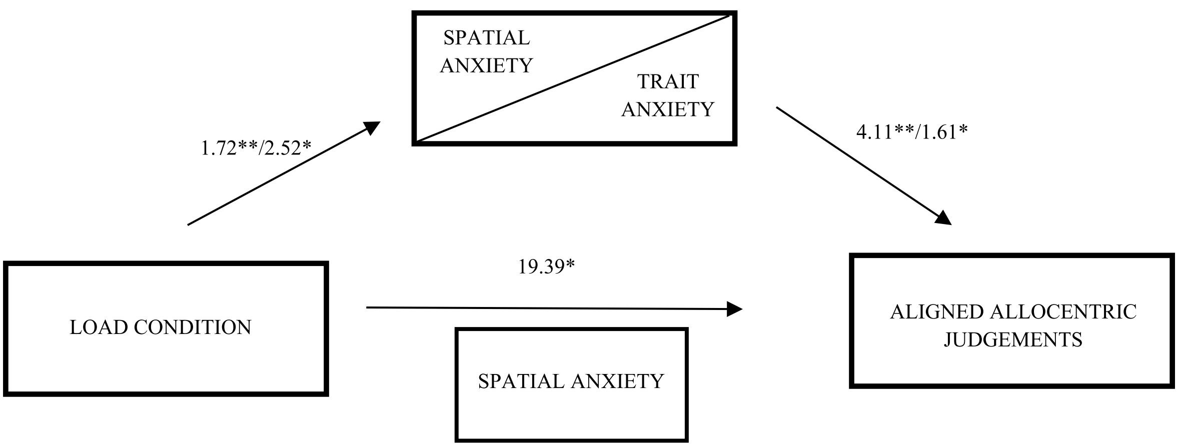

Fig. 3. Mediation graph analysis considering cognitive load as a predictor, anxiety as a mediator and aligned allocentric judgement errors as the dependent variable.

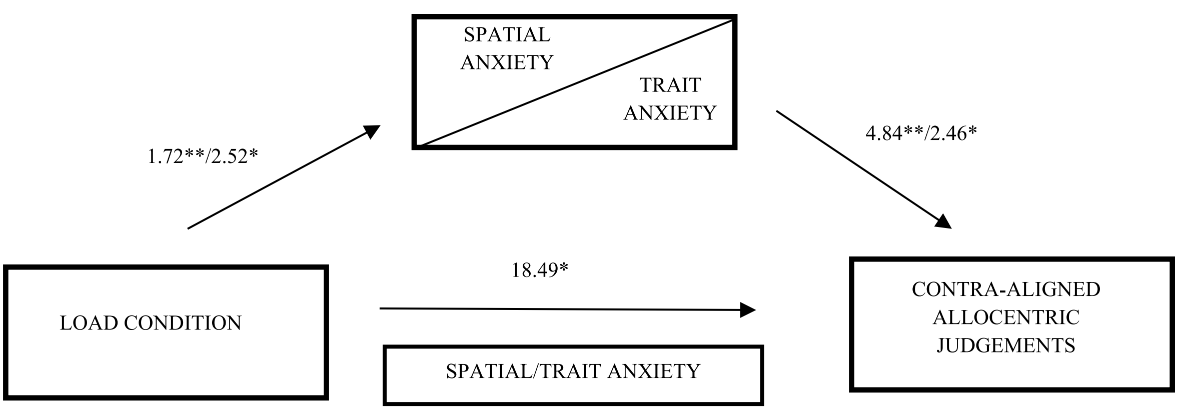

Fig. 4. Mediation graph analysis considering cognitive load as a predictor, anxiety as a mediator and contra-aligned allocentric judgement errors as the dependent variable.

navigation ability remains unknown. The role of virtual environment cognitive load is also scarcely studied (Armougum et al., 2019).

Information processing generates cognitive load, which in turn affects the ability to learn and represent information (Sweller, 1988) and the volume of information recalled (Kirsh, 2000), even if the information is irrelevant (Zucchelli et. a1., 2021). Here, we considered the intrinsic environment cognitive load, related to the presence or absence of irrelevant elements (the presence or absence of people in the environment), mediated by a germane cognitive load (i.e., the participants' anxiety, either trait, state or spatial), to analyse the ability to acquire and represent spatial information. Specifically, we used a behavioural measure to study the impact of cognitive load mediated by anxiety, likely building recognition and egocentric/allocentric references, which have the main advantage of considering individual differences in information processing (Armougum et al., 2019). Indeed, the three tasks require a different cognitive load, ranging from low to high. Regardless of their anxiety level, participants were required to pay attention to different environmental details in more or less complex situations (with or without irrelevant elements).

Our findings confirmed the intrinsic cognitive load effect on VR, but only when people were required to solve complex environmental problems. According to Siegel and White's Model (1975), spatial knowledge requires different steps: a landmark phase, in which individuals recognize environmental landmarks on the basis of physical features; a route-egocentric phase in which individuals add verbal labels to the landmarks to reach a destination; and a survey-allocentric phase, in which individuals develop a map-like representation of the environment. In line with this seminal model, landmark recognition is easier than egocentric and allocentric judgements, whereas egocentric judgements are easier than allocentric judgements. Landmark recognition measures figurative memory and could be considered a task requiring fewer cognitive resources because it does not involve spatial transformation ability (Nori & Piccardi, 2011). Since the cognitive resources required by the task are low, there are no differences in environmental cognitive load. In contrast, in egocentric judgements, the intrinsic navigational cognitive load impacts and worsens performance: the higher the environmental cognitive load is, the worse the performance will be. In this task, people were required to memorize paths and connections among landmarks relying on body references. The cognitive demand required by this task is greater than that required for the previous task, and the participants' cognitive resources fail as the cognitive load increases (high intrinsic cognitive load). This relationship is partially mediated by spatial anxiety. The spatial anxiety contribution to egocentric tasks is well known being positively correlated with the use of egocentric references (Lawton & Kallai, 2002; Hund & Minarik, 2006), such as route strategies, and generally related to lower spatial expertise (Lawton, 1994). However, the mediating role of spatial anxiety in the intrinsic cognitive load and the use of egocentric references remains unclear. Our results showed a specific, partially mediating role of spatial anxiety in the relationship between environmental load and spatial skills. Similarly, cognitive resources are greater in the contra-aligned judgements because participants are required to imagine landmarks that are behind them and then rotate their mental map of the square to obtain a different perspective. In other words, participants must redefine the relationship between the landmarks by manipulating and transforming spatial information, which requires substantial cognitive resources (Coluccia & Louse, 2004). Spatial and trait anxiety partially mediate allocentric judgements: the greater the intrinsic cognitive load is, the greater the elicitation of specific and more general kinds of anxiety will be.

In summary, when participants suppressed irrelevant information, high levels of spatial anxiety resulted in greater difficulties. Therefore, anxiety mediated the relationship between intrinsic cognitive load and performance in all tasks involving subject-to-object or object-to-object relationships. As highlighted by Lawton (1994; 1996) and Kozlowski and Bryant (1977), spatial anxiety can reduce the ability to focus on cues essential for maintaining a sense of direction. Indeed, previous literature indicates that anxiety and spatial reasoning require the use of the visuospatial component of working memory (Gabriel, Hong, Chandra, Lonborg, & Barkley, 2011; Hyun & Luck, 2007). Anxiety reduces working memory resources, which are already engaged in navigating spatial environment demands (Alvarez-Vargas et al., 2020; Eysenck & Calvo, 1992; Kyllonen & Christal, 1990). The negative relationship between spatial anxiety and mental rotation (i.e., contra-aligned judgements) was also shown by Alvarez-Vargas et al. (2020). Our results also demonstrated a contribution of trait anxiety only when the spatial task requires higher spatial skills. Some studies have shown that trait anxiety affects spatial tasks by affecting attention and concentration (Bishop, 2009; Vytal, Cornwell, Letkiewicz, Arkin, & Grillon, 2013). In contra-aligned judgements, cognitive resources are stressed due to the high complexity of the environment and the difficulty of the spatial task. In this situation, different kinds of anxiety were mediators: generalized anxiety, which impairs attention and concentration, and specific (spatial) anxiety, which contributes to worsening performance.

These findings allow us to update the Environmental Knowledge Model (EKM, Nori & Piccardi, 2011), which describes the individual and environmental factors underlying human navigation. In Nori and Piccardi's original model (2011), both familiarity with the environment and spatial strategies played a key role in acquiring and representing spatial information, and their different involvement levels depend on the task demands. No gender differences emerged as a predictor. However, the present study updates the model by introducing a double contribution of external and internal characteristics (see Fig. 5). According to the EKM, solving correctly complex spatial problems is directly predicted by spatial strategies and familiarity with the environment. The new EKM-2.0 model introduces the contribution of an external predictor, i.e., the environmental cognitive load, that directly predicts both egocentric and allocentric spatial tasks. Furthermore, it considers spatial and trait anxiety, which mediate the relationship between environmental complexity and spatial competence. We also introduced the relationship between environmental load and familiarity with the environment, as analysed by Armougum et al. (2019).

5. Conclusion

Our results suggest the importance of considering individual differences, such as spatial and trait anxiety levels in spatial orientation, to improve navigational skills in complex environments. The early diagnosis and treatment of spatial anxiety and anxiety traits could have repercussions on the individuals' quality of life by improving their autonomy and confidence in environmental displacement. Future studies should also investigate the presence of these traits in developmental topographical disorientation, a neurodevelopmental disorder affecting 3% of healthy young people (Piccardi et al., 2022) that greatly limits social interactions and achievement. Moreover, it could be useful to consider anxiety and environmental cognitive load in older people; indeed, several studies have suggested that the impact of anxiety on cognition could be moderated by ageing (Charles & Luong, 2013).

On the basis of these results, it could also be useful to develop specific training to reduce spatial anxiety, for example, using a mindfulness-based anxiety reduction technique (Call, Miron, & Orcutt, 2014). Anxiety-reduction training could also be beneficial in the presence of atypical ageing by allowing patients to access all their cognitive resources that are further reduced by anxiety.

However, this study is not without limitations. First, the anxiety level was measured using self-rated scales instead of physiologic parameters, such as the galvanic response, heart rate and shortness of breath. These measures could provide an objective evaluation of physiological changes related to subjective feelings. Additionally, future studies should also detect these parameters to understand the level of arousal experienced by participants with anxiety compared with that in participants with a reduced level of anxiety when performing the same task in VR. Finally, anxiety related directly to VR was not measured and future studies should measure the extent to which performing a task in VR increases anxiety and relate it to navigational performance.

In conclusion, this work emphasizes how both internal and external factors jointly explain navigational performance and contribute to worsening performance of individuals with navigational disorders.

Funding sources

This research was not supported by any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

R.N.: Conception and design of study, Methodology, Drafting the manuscript, Approval of the version of the manuscript to be published.

M.M.Z.: acquisition of data, analysis and/or interpretation of data, revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published.

M.P.: analysis and/or interpretation of data, revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published.

L.P.: Conception and design of study, Methodology, Reviewing and Editing, Supervision, revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published.

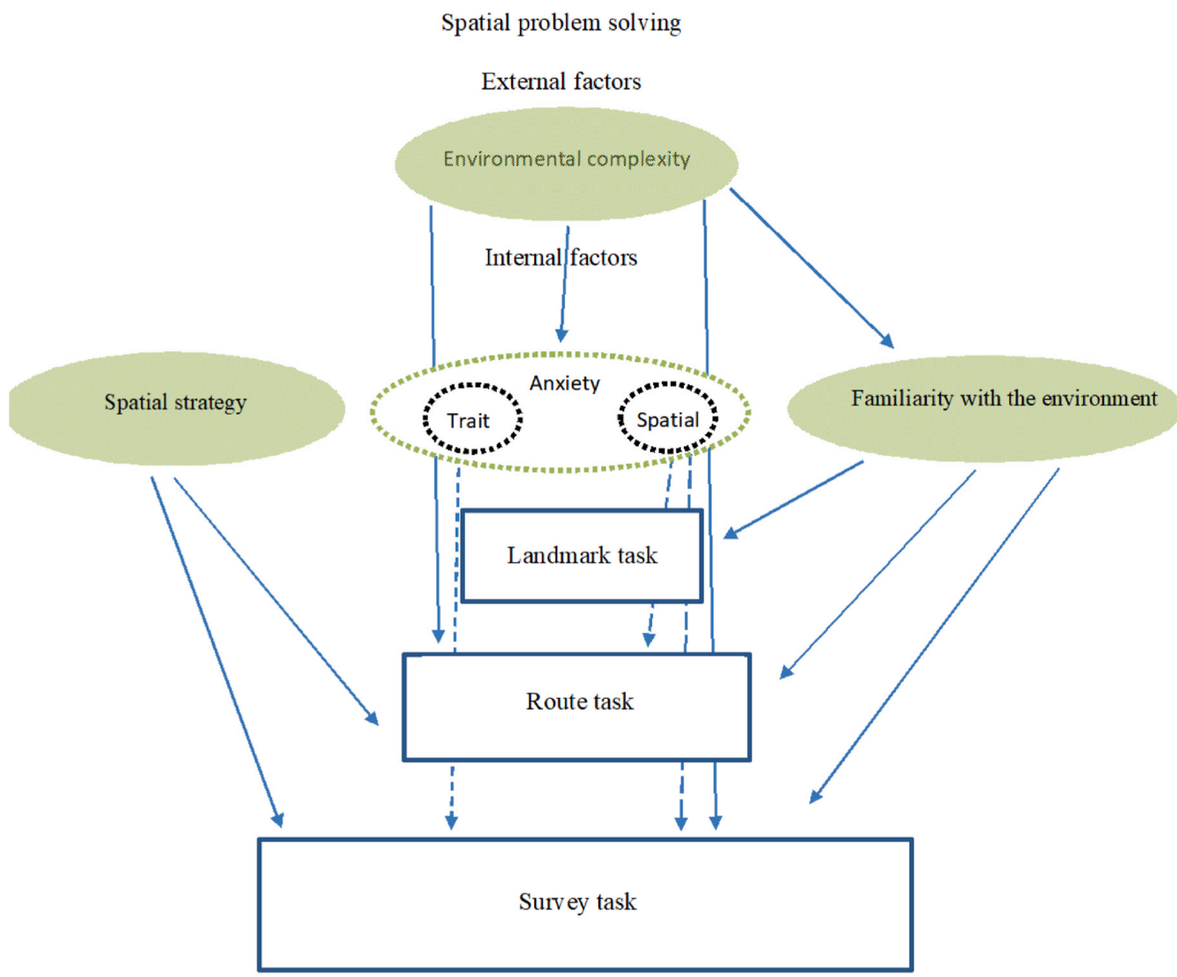

Fig. 5. The EKM-2.0. The figure depicts the external and internal predictors for correctly solving different spatial problems. The rectangle of the problems describes the cognitive recourse necessary to solve it: the larger the rectangle is, the more cognitive resources are required. The traced arrows describe mediations, whereas the non-traced arrows describe direct predictors. The same is true for the circles that describe external and internal factors.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgements

All persons who have made substantial contributions to the work reported in the manuscript (e.g., technical help, writing and editing assistance, general support), but who do not meet the criteria for authorship, are named in the Acknowledgements and have given us their written permission to be named. If we have not included an Acknowledgements, then that indicates that we have not received substantial contributions from non-authors.

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