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Research report

Spatial memory in young adults: Gender differences in egocentric and allocentric performance

C. Fernandez-Baizan[a,b], J.L. Arias[a,b], M. Mendez[a,b,*]

[a] Department of Psychology, University of Oviedo, Spain
[b] Instituto de Neurociencias del Principado de Asturias (INEUROPA), Spain

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ABSTRACT

Spatial memory allows us to locate objects and organisms in space and move through the environment. We frequently use two strategies for this purpose: egocentric, related to the viewer's perspective, and allocentric, associated with environmental cues. This ability is usually assessed by 2D or virtual reality-based tasks. Gender differences have been reported on these tasks. We designed two card-placing tasks with the aim of assessing egocentric and allocentric spatial memory in a real environment. This task makes it possible to separately compare egocentric and allocentric strategies, providing participants with 3D information naturally present in daily orientation activities. We will assess the performance of male and female young adults on the two strategies. Ninety-four subjects were recruited and performed egocentric and allocentric spatial memory card placing tasks. Spatial Span, forward and backward, was also assessed using the Cambridge Neuropsychological Assessment Battery (CANTAB), and the brief version of Benton's Judge of Line Orientation Test (JoLO) was used to evaluate the ability to judge spatial relations. Our results show that men outperformed women on both spatial memory tasks. Women performed better on Allocentric tasks than on Egocentric tasks, whereas men's scores did not show differences between strategies. Spatial memory performance on the card placing tasks was significantly correlated with performance on the backward visuospatial span from the CANTAB. This study supports the existence of gender differences in spatial memory functioning, and it provides novel tools for the neuropsychological assessment of spatial memory.

1. Introduction

The space where humans move is often occupied by objects and other organisms, and so it is indispensable to take their positions into account when planning our movements, carrying out behaviors, or evaluating what is happening in the environment at any given moment [1]. Spatial cognition is a function that has to do with "knowledge and beliefs about spatial properties of objects and events in the world" [2]. This knowledge starts up when humans navigate through the environment in a function called spatial orientation: the ability to follow a path through the environment in order to find a target location [3]. For this purpose, we can locate and reorient ourselves with regard to our own organism – the egocentric strategy – or independently of the viewer's position – the allocentric strategy - [4]. The former requires the ability to use our internal cues – distances, turns, and directions – and follow and update our movements [5]. The latter involves remembering elements in the environment, and it eventually allows us to create representations of our world – through mapping – [6,7]. Both strategies are necessary for fully functional spatial navigation, and so we frequently switch, integrate, and combine them [8].

Correct functioning of other systems is required for spatial orientation performance. We need to perceive sensorial and proprioceptive stimuli in order to identify our surrounding environment and our own location in it. We first need to memorize information and then remember it, so that we can reorient ourselves in previously known places, and we have to plan our own orientation strategies or our own spatial routes to reach a target location [9]. Thus, spatial navigation is a complex capacity that requires the participation of other information and processes. Currently, spatial orientation is mainly assessed using virtual reality or computed-based tasks [10–13]. These tests are useful and easy to administer, and they allow the examiner to control and manipulate variables such as complexity, time response, the available cues, or the path followed by the participant, all of which help to improve our knowledge about spatial orientation in humans. However, it seems that some vital stimuli that are present in daily spatial orientation activities, such as proprioceptive, somesthetic, or vestibular

* Corresponding author at: Faculty of Psychology, Plaza Feijoo s/n, 33003, Oviedo, Asturias, Spain.
E-mail address: mendezlmarta@uniovi.es (M. Mendez).

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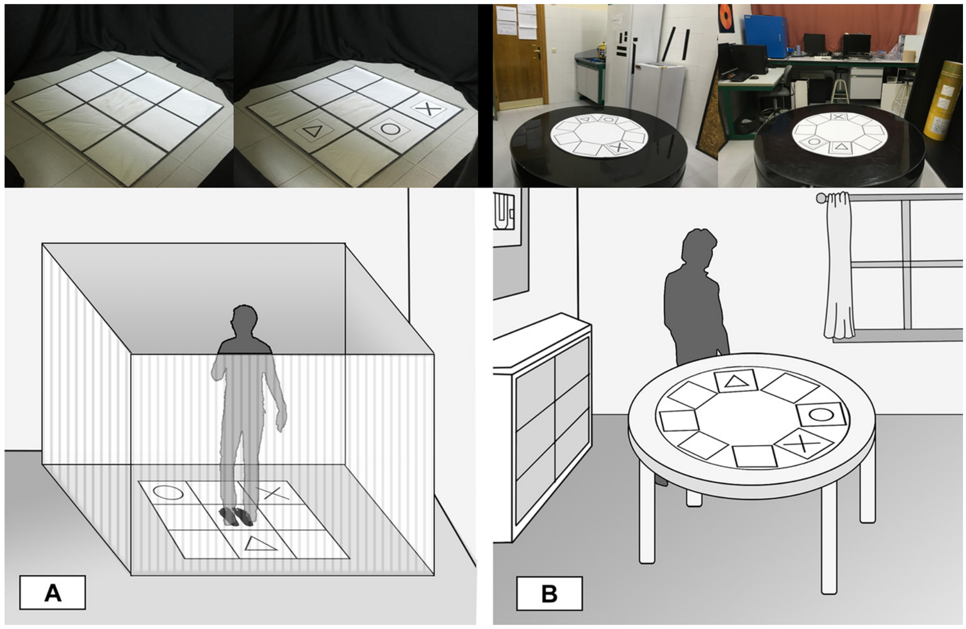

Fig. 1. Representation of experimental conditions of the Egocentric Spatial Memory Task (A) and the Allocentric Spatial Memory Task (B).

information, are not available on computerized tasks [14,15]. A few studies have used other tasks that allow participants to move and perceive all this 3D information usually present in real environments [15–17], even combining them with new technologies, as in augmented reality [18]. However, no virtual tests or real world tests are used to compare performance on the two types of spatial strategies, egocentric and allocentric, because their main aim is usually to compare ages and/or genders. Therefore, these tasks do not make it possible to know whether participants eventually solve the task using one framework, the other framework, or a combination of the two. In addition, on the one hand, we know that the egocentric strategy appears earlier in babies [19], whereas the allocentric framework does not appear until two years of age [20] and is not fully developed until the age of seven [21]. On the other hand, studies have shown that the egocentric strategy does not decline until 60 years old, and the allocentric strategy until 70 years old [22]. Thus, we can expect that in adults, especially young adults, there are no performance impairments if we compare the two frameworks.

Gender differences are frequently found on spatial memory tasks, where men usually outperform women, with a lower response latency or better adaptation to increases in difficulty [10–12,23,24]. However, this performance depends on the presence of other variables: the type of cues available, previous experiences, or familiarity with the environment [15,17,25,26]. The strategy followed is also important: for example, men seem to prefer to use Euclidean information, whereas women usually trust in landmarks [27–30]. Thus, we can assume that gender could have an influence on the performance of one strategy over the other. Previous studies have found that egocentric performance remains equal between genders, but men achieve better scores than women in allocentric conditions [31]. Moreover, gender differences have been found in other visual and spatial capacities, such as mental rotation [28] or visual span [15]. Therefore, these kinds of abilities must be taken into consideration in interpreting gender divergence.

The aim of this study was to examine gender differences in spatial memory in a young adult population using a real world-based task. This task makes it possible to compare the egocentric and allocentric strategies separately, providing participants with 3D information naturally present in daily orientation activities. This task could be useful for neuropsychological assessment in adults as a way to introduce ecological and functional tasks into regular cognitive evaluations. Because spatial orientation is a complex process, we also employ some visual and spatial neuropsychological standardized tests for comparison in our studied population. We hypothesized that men would outperform women on egocentric and allocentric tests, as well as on visuospatial neuropsychological tasks. Men would have better performance on allocentric tasks than on egocentric tasks, whereas egocentric vs. allocentric differences would not appear in women.

2. Material and method

2.1. Participants

The sample was composed of 94 subjects, 47 males (20.98 ± 3.791) and 47 females (19.74 ± 2.1 years). Subjects were students from the University of Oviedo (Spain) that participated voluntarily in the study. Exclusion criteria included some circumstances that could potentially interfere with performance, such as neurological disorders, psychiatric problems, or intellectual disability. IQ was checked using the *Reynolds Intellectual Screening Test (RIST)* [32], dismissing participants who did not reach a score of ≤ 85 points. All the subjects were given information and provided their written consent before the experiment began. This study was conducted in compliance with the European Community Council Directive 2001/20/EC and the Helsinki Declaration for biomedical research involving humans.

2.2. Materials

2.2.1. Egocentric spatial memory test

This task is a purely egocentric adaptation of the Hashimoto test [33]. It consisted of a squared template (105 × 105 cm.) divided into nine squares (3 × 3 each 35 × 35 cm.) and placed on the floor. The subject was located in the center of the matrix and three cards (circle, triangle, and cross) were employed as stimuli. In our version, we include four opaque panels (280 × 205 cm.) that were arranged in a square around the subject, to prevent any visual information that could guide task performance (See Fig. 1.A).

2.2.2. Allocentric spatial memory test

This test was performed on a round table where a round template (95 cm. of diameter) was placed. Eight possible locations were drawn on this template, marked as squares along its perimeter. Three cards (circle, triangle, and cross) were employed as stimuli. This task was conducted in a regular rectangular room with all the usual furniture and objects visible to the participant (See Fig. 1.B).

2.3. Procedure

The experiment took place in the Faculty of Psychology, Oviedo. Participants were informed about the tasks and tested individually by trained psychologists. All procedures were performed in a session lasting 60 min. Assessment began with the Reynolds Intellectual Screening Test (RIST), followed by Benton's Judge of Line Orientation Test, Spatial Span from Cambridge Neuropsychological Assessment Battery (CANTAB), Allocentric Spatial Memory Test and Egocentric Spatial Memory Test.

2.3.1. Egocentric spatial memory test

Each subject was placed in the center of the template located inside 4 opaque panels, in order to force him/her to employ body position as a reference and avoid environmental cues. We evaluated the ability to memorize the spatial placement of objects located on the floor around the participant. This task had two parts. In part A, the participant stood in the center of the squared matrix and was asked to remember the position of three cards (circle, triangle, and cross) placed in one of the eight positions surrounding him/her. The evaluator removed the cards after a 10-second delay and told the participant to return them to their previous location (See Fig. 2.A). In part B, the participant had to remember the location of the same three cards, but after the cards had been removed, he/she was rotated to the right or left by 90° or 180° and then told to put the cards back in the same position (See Fig. 2.B). During the task, the participant could see all changes made in the placement and removal of the cards, as well as his/hers own turns. On each part, the participant could score 30 points. Therefore, each subject could obtain between 0 and 60 points in total.

2.3.2. Allocentric spatial memory test

On this task, we assessed the ability to represent the spatial placement of objects using distal environmental cues. The participant stood in front of a round table with 8 possible locations, indicated with squares. In the sample trial, the examiner put the circle, triangle, and cross cards on three of these squares and asked the participant to

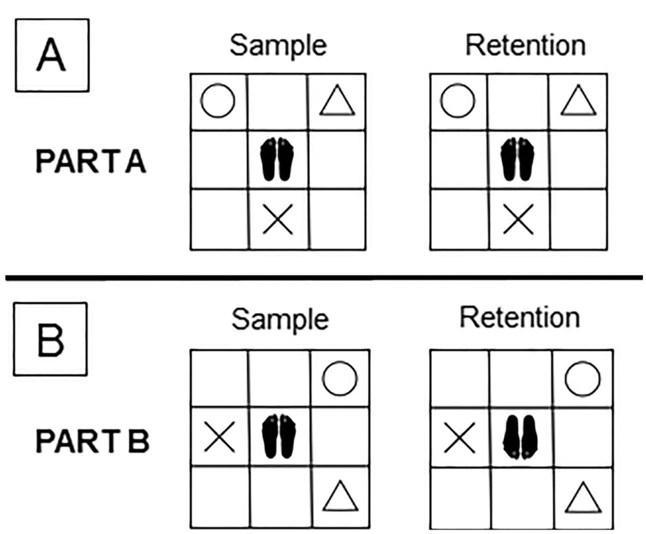

Fig. 2. Example of Egocentric sample and retention trials of Part A (A) and Part B (B) of the Task. In Part A, the participants stayed in the same position throughout the sample and retention trials, whereas in Part B, they rotated to the right or left 90° or 180° after the sample trial. The subject scored 1 point for each card placed correctly.

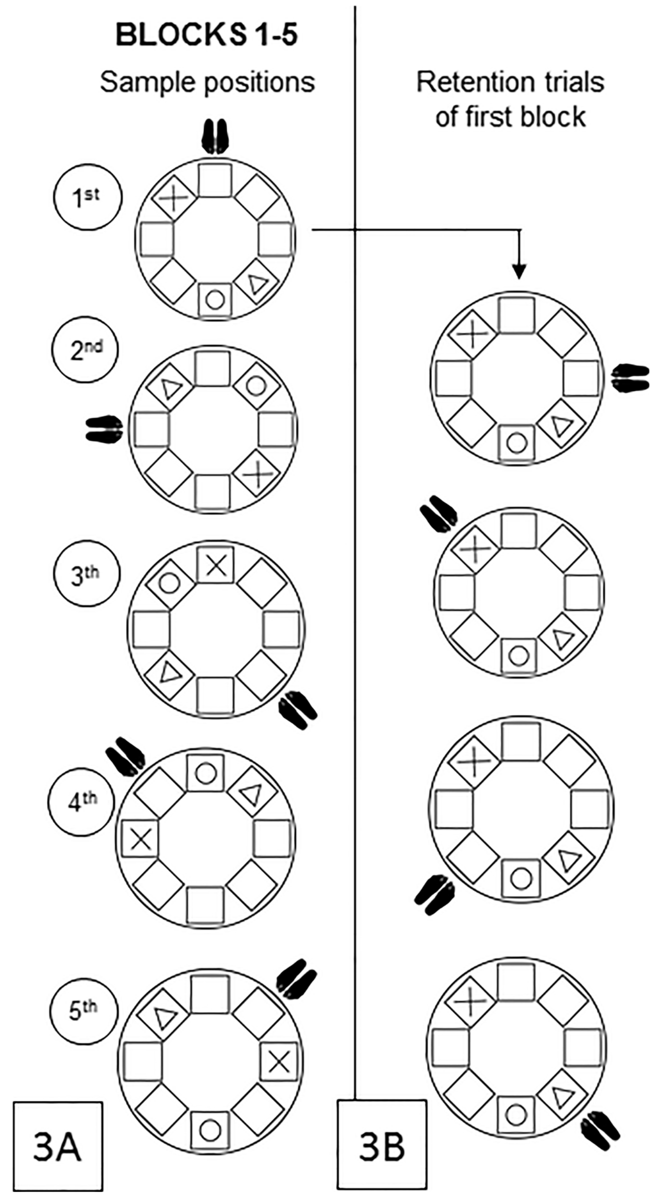

Fig. 3. Position of cards in the five blocks of the Allocentric Task (A). Each block consisted of a sample where the participant was shown the card's location for the first time and 4 retention trials where the subject was moved to a new position in each trial (B). The location of the cards did not change in every block but it was different between them. The subject scored 1 point for each card placed correctly.

remember their location. After 10 s, the subject was blindfolded, and the evaluator moved him/her by walking around the table to another location. From this new position, in every retention trial, the participant was told to return the three cards to their previous location. If the subject made any mistakes, the examiner corrected him/her and indicated the right position. The test consisted of 5 blocks of 4 trials each (See Fig. 3A), where the location of the 3 cards on the table was the same in each block and repeated in 4 retention trials, even though the participant was moved to a different position in each trial (See Fig. 3B). On each block, the participant could score 12 points, so he/she could obtain between 0 and 60 points in total.

2.3.3. Benton's judge of line orientation test

The Brief version of the TF 2/3 H11-30 was used to evaluate the ability to judge spatial relations. The subject was asked to match the two lines at the top with the corresponding 11 lines at the bottom, displayed in a radial form [34]. The maximum score was 30 points.

2.3.4. Spatial span (forward and backward) - Cambridge neuropsychological assessment battery (CANTAB)

We assessed visuospatial span in the Forward version and visuospatial working memory in the Backward version [35], based on the Corsi block-tapping test. On a touchpad, the participant was shown some white squares, some of which were going to light up in a specific order. The subject was asked to touch them in the same order on the Forward task, and in the opposite order on the Backward task. The test started with 2 span items, adding 1 additional item in the following trials until reaching 9 squares; therefore, the maximum score in each part is 9 points. The task allowed the participant to repeat the same span as in the previous trial if he/she made a mistake. If the participant committed three errors with the same span items, the task ended.

2.4. Statistical analysis

Analyses were performed with SigmaStat software version 3.2 (Systat, Richmond, USA). Saphiro-Wilk was used to test normality and Levene was employed to check homogeneity. T-tests were used to compare genders and Egocentric and Allocentric scores. Repeated-measures ANOVAs were used on the Allocentric task to evaluate improvement across blocks of trials, using Holm-Sidak for post hoc analysis. Bivariate Pearson correlation analysis was performed to assess relationships between the spatial orientation tasks and the neuropsychological variables. The *Cohen's d effect size was reported for every comparison (d).* Differences were considered significant for $p < 0.05$.

3. Results

Saphiro-Wilk and Levene tests have shown that our sample has normal distribution and homogeneity of variances ($p > 0.05$). *T*-tests revealed a significant main effect of Gender on Egocentric A ($t92 = -2.436$, $p = 0.017$, $d = 0.503$), Egocentric B ($t92 = -3.289$, $p = 0.001$, $d = 0.678$), Allocentric ($t92 = -2.319$, $p = 0.005$, $d = 0.591$), Spatial Span Forward ($t92 = -2.225$, $p = 0.029$, $d = 0.459$) and Spatial Span Backward ($t92 = -3.831$, $p < 0.001$, $d = 0.790$). JoLO did not show significant Gender differences ($p = 0.257$) (See Table 1).

In the whole sample, paired *T*-tests revealed significant differences between Egocentric and Allocentric performance ($t93 = 2.595$, $p = 0.011$, $d = 0.303$). Although men's scores did not show differences between the strategies ($p = 0.145$), women obtained different results with better scores on Allocentric tasks than on Egocentric tasks ($t46 = 2.126$, $p = 0.039$, $d = 0.392$) (See Fig. 4).

Comparing the Allocentric blocks, T-tests showed a significant effect of Gender on the first ($t92 = -2.655$, $p = 0.009$, $d = 0.547$) and fifth blocks ($t92 = -2.036$, $p = 0.045$, $d = 0.420$), where men scored better than women. Repeated-measures ANOVAs showed a significant effect

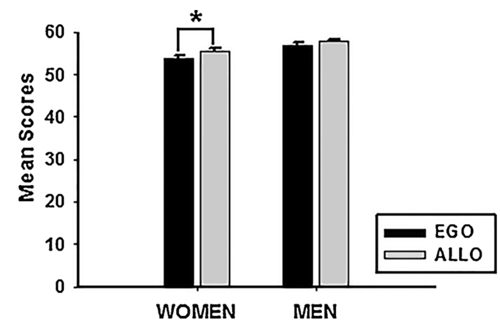

Fig. 4. Mean Egocentric (EGO) and Allocentric (ALLO) scores in Women's and Men's groups. Significant differences were found between EGO vs. ALLO in Women (*$p < 0.05$), with higher scores on Allocentric than Egocentric.

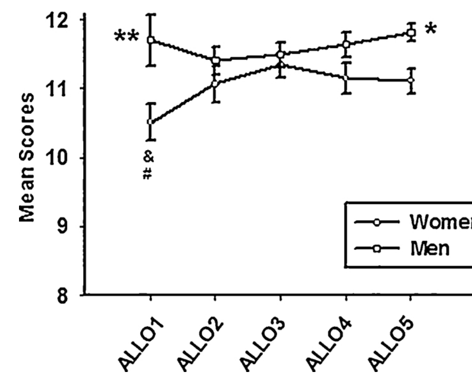

Fig. 5. Mean scores on the Allocentric blocks (1–5) in the Women's and Men's groups. Significant differences between Men and Women were shown in the first and fifth blocks (*$p = 0.045$; **$p = 0.009$, respectively). Improvement across the blocks of trials was also shown in the group of Women. The fifth and third blocks were better than the first (&$p = 0.036$ and #$p = 0.032$, respectively).

of learning in women ($F4,184 = 2.932$, $p = 0.022$, $\eta 2 = 0.191$). In the women's group, post-hoc Holm-Sidak analysis revealed that scores on the third and fifth blocks were better than on the first block ($t = 2.986$, $p = 0.032$, $d = 0.548$ and $t = 2.912$, $p = 0.036$, $d = 0.544$, respectively). Men did not show differences across Allocentric blocks ($p = 0.689$) (See Fig. 5).

Correlation analysis showed significant relations between Backward Spatial Span and Part B of the Egocentric task ($r = 0.344$ $p = 0.003$) with a medium correlation level. Backward Spatial Span was also significantly correlated with the Allocentric task ($r = 0.309$ $p = 0.003$) with a medium correlation level (See Table 2).

Table 1
Mean and SD for tests scores in Gender groups.

Tasks	Females Mean (SD)	Males Mean (SD)	*p* value
EGOA	29.09 (1.33)	29.66 (0.92)	0.017
EGOB	24,57 (4.01)	27.21 (3.77)	0.001
ALLO	55.43 (4.46)	57.74 (3.29)	0.005
JoLO	25.07 (4.88)	26.06 (3.41)	0.257
SSP-F	7.23 (0.96)	7.83 (1.56)	0.029
SSP-B	6.28 (1.19)	7.47 (1.77)	< 0.001

EGOA Egocentric Spatial Memory Task part A; EGOB Egocentric Spatial Memory Task part B; ALLO Allocentric Spatial Memory Task; JoLO Benton's Judge of Line Orientation Test; SSP-F Spatial Span Forward; SSP-B Spatial Span Backward.

Table 2
Correlation of Egocentric and Allocentric Spatial Memory Tasks with Benton's Judge of Line Orientation Test and Spatial Span Forward and Backward from CANTAB.

Tasks		JoLO	SSP-F	SSP-B
EGOA	Pearson Correlation	.047	.113	.128
	p value	.654	.277	.221
EGOB	Pearson Correlation	.109	.189	.304**
	p value	.302	.068	.003
ALLO	Pearson Correlation	.028	.199	.309**
	p value	.791	.055	.003

EGOA Egocentric Spatial Memory Task part A; EGOB Egocentric Spatial Memory Task part B; ALLO Allocentric Spatial Memory Task; JoLO Benton's Judge of Line Orientation Test; SSP-F Spatial Span Forward; SSP-B Spatial Span Backward.

4. Discussion

In this study, two tasks were tested in young adults to analyze gender differences in their performance on the two spatial orientation strategies, egocentric and allocentric, trying to approach the natural conditions (self-movement, optical flow, proprioceptive stimuli, etc.) that appear in daily navigational activities. These tasks allow us to compare performance on the two strategies, whose differentiation could be useful for mnesic impairments or the diagnosis of topographical disorientation. In addition, they provide participants with the opportunity to visualize reality without 2D or virtual images, avoiding the use of the computer or other devices that could require previous understanding of their handling in some populations.

This study shows that men outperform women on Egocentric and Allocentric spatial orientation. These results are consistent with previous studies, where males usually outperform females on virtual navigation tasks [10–12,23,24] as well as on real world-based tasks [22,29]. This gender divergence has been related to several variables. First, men and women seem to show different brain activation patterns during spatial orientation: more right-lateralized activation in the posterior hippocampus has been found in men [23,36], whereas women recruit the right parietal and right prefrontal cortex [37]. Higher activation or greater volume in the hippocampus has been related to spatial navigation in professional drivers [38], whereas patients with hippocampal damage perform worse on these kinds of tasks [39]. Thus, it seems that greater involvement of the hippocampus allows men to perform better on spatial navigation. Another possibility is related to hormones, specifically testosterone, which seems to play an important role in spatial orientation: lower levels impair women's performance [40], whereas higher levels are related to better scores in men [12]. Moreover, testosterone has been related to men's improvement on other spatial abilities, such as mental rotation [41]. Therefore, better performance by men on spatial orientation could be due to biological reasons, such as brain activity patterns or hormonal levels.

Women have shown higher scores on the Allocentric strategy than on the Egocentric strategy, but men's performance remains equal in both frameworks. In other studies, when the spatial task allowed the participants to choose which strategy they preferred, women chose an egocentric strategy, whereas men employed an allocentric strategy [31]. Thus, although it seems that women usually prefer an egocentric framework, allocentric outperforms egocentric in our tasks. However, in spite of Egocentric task only allow employing egocentric strategy, we cannot discard than during Allocentric task women could also have used egocentric information. Although our aim was to recreate as close as possible a pure allocentric strategy, we could not be sure about the participant's strategy used in this Allocentric task. Participants can perceive their movements and their vestibular information, even if they are blindfolded. Therefore, these results could indicate that women use allocentric strategy better than egocentric, but a combination of both strategies during Allocentric test is also a possible explanation for the results. Another option is that worse scores on the Egocentric test could be due to the absence of real environmental information during the test. We need to consider that when spatial navigation is carried out in a version of the Morris Water Maze, as in most virtual spatial orientation assessments, egocentric responses are associated with reorientation with local landmarks, whereas allocentric responses are related to the spatial layout. However, our Egocentric test is as pure as possible, without any local or distal environmental cues, thus leaving participants to reorient themselves with their own turns. Previous studies have found that females employ landmarks, whereas men use Euclidean information [27–30], but on our Egocentric task, women have no access to environmental cues. Therefore, our study supports the idea that women employ landmarks for spatial orientation, but because the Egocentric test does not allow them to use environmental information, females achieve better scores on the Allocentric test, where cues are available. However, our Egocentric task did not keep men from calculating distances or proportions if they wanted to. This means they could employ Euclidean information, which could be the reason men perform equally on Egocentric and Allocentric tasks.

Gender divergences appear in different Allocentric trials: males score better than females in the first and fifth trial. Moreover, the learning achieved during the Allocentric test differs between genders: women show improvement across trials, but men do not. Men's results are not surprising because they almost reach a ceiling effect in all the trials of the Allocentric test, which means that no learning effect appears because they almost get maximum scores on the fifth trial. Future studies could include an increase in task difficulty for males in order to analyze their spatial learning capacities. However, women do show improvements on the third and fifth trials. The first trial yields the lowest score for the women's group, compared to other trials and compared to men. Although the examiner gave the participants the instructions and the procedure for the task beforehand, they were never told how to solve the task; in other words, the subjects were not told if they needed to pay attention to environmental cues to perform the task correctly, and so they had to figure it out. These results could indicate that, whereas men discover the right strategy to solve the task on the first attempt, women need more time or more trials to realize how to locate the cards correctly. For example, women seem to show an exploratory behavior on real world-based tasks [17] that involves an increase in the time doing the test. In addition, it seems that if women have enough time to remember spatial information, more than men usually need, gender differences disappear [25], and spatial navigation in unfamiliar environments seems to impair reorientation performance, especially in women [42]. Therefore, not having enough time to remember all the spatial information linked to being in an unknown location could have affected women's performance. On the third trial, men's and women's scores were equal, which shows that when women are given enough time and trials, their performance does not differ from that of males. Future perspectives could include manipulating the time of exposure or previous familiarity with the environment in female participants. However, on the fifth trial, we can observe how women's performance decreases again, compared to their own performance and compared to men's. Gender divergences in spatial orientation performance usually appear when task difficulty increases [43], but not when the task remains in easier stages. However, our Egocentric and Allocentric tests do not become more complex across trials. This could mean that, even if we do not change the difficulty deliberately, women could find the last Allocentric trials harder than previous ones. Accumulative fatigue could explain this rise in complexity perceived by women. If the spatial memory task involves high integration and imagined transformation of the visual material [25], as the Allocentric task does, the difficulty for women increases. Therefore, sustaining this complex process across the 20 trials of the Allocentric test could be a great effort for female participants that could affect their later trial performance.

Visuospatial working memory seems to play a vital role in spatial orientation performance, especially in women. On the one hand, we find that visuospatial span and visuospatial working memory show differences between genders, where males again outperform females. These results have been replicated in previous studies [44,45], and they have been related to processing speed [46] and different patterns of brain activity [47]. On the other hand, we find that both Egocentric B and Allocentric scores correlate with visuospatial working memory scores. In other words, a certain part of spatial orientation performance could be due to visuospatial working memory achievement. As mentioned above, women perform worse on this function, which has been related to spatial orientation [15].

5. Conclusion

In this study, we have administered novel spatial orientation tasks, trying to recreate the natural conditions of daily spatial navigation, but separately assessing the two frameworks, egocentric and allocentric, employed to reach the target locations. In young adults, we found that men outperform woman on Egocentric and Allocentric tests, as well as on visual and spatial abilities such as visuospatial span and working memory. This could have influenced the female spatial orientation results. Contrary to what was expected, men perform equally well on both Egocentric and Allocentric strategies, but women achieved better scores on Allocentric tasks than on Egocentric tasks, probably due to their preference for the use of landmarks for reorientation. These tasks could become useful tools for the assessment of spatial memory ability and the use of allocentric and egocentric strategies.

Conflict of interest

Authors report no conflicts of interest regarding the publication of this manuscript.

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