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RESEARCH ARTICLE

Reversal Training Discloses Gender Differences in a Spatial Memory Task in Humans

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Abstract

Background: Over the past few years spatial memory has been studied using virtual reality-based tasks. Reversal learning has been widely used in spatial orientation tasks for testing, among other things, new learning and flexibility.

Methods: By means of a reversal-learning protocol, we assessed spatial memory in men and women. A total of sixty participants (half of them women) performed a task that included two phases: during the acquisition phase participants were asked to find one or three rewarded positions in the virtual room along ten trials. During the reversal phase rewarded boxes were moved to a new position and maintained for four trials.

Results: Results showed that men and women differed in the reversal phase with men outperforming women.

Conclusion: Dissimilarities in several cognitive abilities between both genders are in the base of these differences and were discussed.

Keywords

Reversal, Flexibility, Dimorphism, Human, Virtual reality

Introduction

Spatial memory is a cognitive ability present in our daily lives. Information about places and objects location is stored in our spatial memory, supported by the hippocampus and other brain structures [1-3]. In many cases, the relocation of objects to new positions challenges our mental flexibility, and requires modifying our actions according to the environmental feedback.

Flexibility has been widely assessed through reversal learning tasks. In accordance with Colman (2015) [4], reversal learning is a form of learning in which an organism choosing repeatedly between two alternatives A and B is initially rewarded for choosing alternative A rather than B until a behavioral preference for A is established, and is then rewarded for choosing B rather than A. Spatial reversal learning has been frequently used in rodent research [5-9]. It consists in changing a spatial target to a new position, demanding subjects to forget old previous spatial information in order to encode a new relationship between target and the cues available. In humans reversal tasks have been highly studied [10,11] but few of them used a spatial context [12] and allocentric tasks [13], which are hippocampus dependent [14,15].

Moreover, performance of both sexes in spatial memory tasks has been deeply studied and it is well known that this cognitive ability is dimorphic [13,16-19]. Men are prone to use a sort of spatial strategies that help them to solve the task successfully. Thus, they are good at forming cognitive maps and doing mental rotation [18,20-23], abilities that are very useful to solve spatial tasks. Maybe for this reason men are prone to use spatial strategies related with Euclidean information [23-25]. As women are better in object location tasks, they tend to select strategies related to the position of

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landmarks available in the environment [25-28]. Thus, allocentric strategies used by men are based on global information such as distances, cardinal points and mental maps, whereas women prefer egocentric reference frames based on detailed information like landmarks available and directions from their own position [27-29]. In addition, task difficulty could determine the appearance of gender differences [30-32]. Accordingly, it is very important to adapt the difficulty level to the sample studied.

In this study men and women were compared in a reversal learning protocol in the Boxes Room Task. The Boxes Room Task [33] is a spatial memory test based on virtual reality technologies. Performance depends on the integrity of the medial temporal lobe [34]. We hypothesized that reversal learning would be more challenging for women in the more demanded test conditions.

Methods

Participants

Thirty men and 30 women from the University of Almeria participated in this study (Table 1). Participants were divided into two groups according to the level of difficulty of the experimental conditions. In the low difficulty protocol, participants had to find one rewarded box, whereas in that with an intermediate difficulty subjects had to find three rewarded boxes (Table 1).

Participants were asked about prior videogame experience (0 = never, 1 = occasionally, 2 = frequently), joystick handling (yes/no) and manual preference. None of them had any neurological disorder, psychological illness, intellectual disability or were on drug treatment which could have affected their cognitive performance. All participants were volunteers and they all agreed to sign the informed consent.

The study was conducted in accordance with the European Communities Council Directive 2001/20/EC and the Helsinki Declaration for biomedical research involving humans.

Apparatus

The Boxes Room task was administered on a Hewlett Packard 2600-MHz notebook with a 15.4 TFT and a color screen (1920 X 1200 pixels). A Logitech joystick was used for the navigation through the virtual task. Visual and auditory feedbacks were emitted by the computer.

Table 1: Distribution of participants between different task conditions.

Sample	Low difficulty	High difficulty
Men (n = 30)	13	17
Age	20.54 ± 2.96	21.59 ± 5.48
Women (n = 30)	13	17
Age	18.54 ± 0.88	20.76 ± 3.95

Procedure

The Boxes Room test is a virtual task in which 16 brown boxes were symmetrically distributed on a square and decorated room [33]. The room included several objects on their walls: the North wall was blank, the East wall had three Leonardo da Vinci's paintings hanging; the South wall displayed some Egyptian ornaments and finally, a door and a window were located in the West wall (Figure 1C). When the participants selected a box, two scenarios were possible: The box turned into green (a rewarded box) or else the box turned into red (a non-rewarded box). Green boxes were also linked to a pleasant tune which started when it was discovered, whereas in non-rewarded boxes a rather discordant tune was heard. Individuals were asked to find those boxes that turned to green when selected (rewarded boxes). Boxes remained green or red during the whole trial. The trial finished when all the rewarded boxes were selected or when the elapsed time reached 150 seconds (maximum trial duration). When a new trial began, all boxes turned brown.

The experimental session consisted of 14 trials, with an inter-trial interval of five seconds. In the first 10 trials, locations of the rewarded boxes remained constant, however, in trial 11 the rewarded boxes changed to a new position (reversal learning) and remained until the end of the experiment (trial 14). There were two experimental difficulty conditions: Low (one rewarded box) and medium (three rewarded boxes), and participants were randomly assigned to them, keeping the same number of male and female participants in each group. As the intention was to facilitate the acquisition phase in both groups, three locations were established as the higher difficulty condition. In this way men and women enjoyed the same learning opportunities before the reversal phase. No information regarding useful strategies, the location of the target boxes, or any other features of the experiment was provided. Participants were not informed about the possibility of boxes relocation. To avoid egocentric solutions four different starting positions were used (North, South, East and West).

Statistical analyses

Accuracy (by number of errors) and latencies (in seconds) during the initial 10 trials were analyzed by ANOVA (Gender x Trial) with repeated measures in the last variable. An analysis of trials 10 to 14 was carried out by using the same statistical procedure. Newman-Keuls test was applied for post hoc analyses. STATISTICA version 8.0 was used. Differences were considered statistically significant for $p < 0.05$.

Results

One rewarded box

Errors

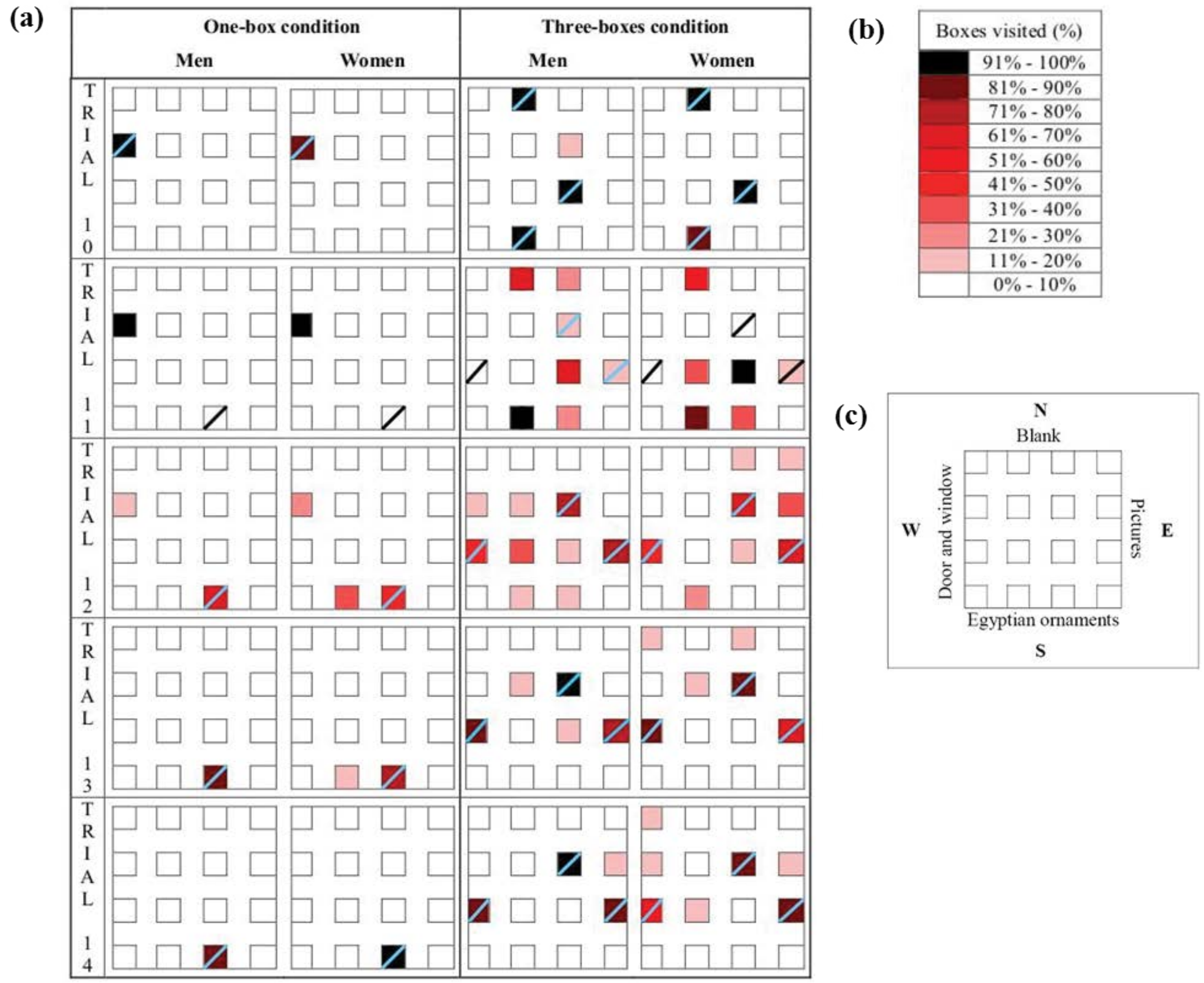

Figure 1: A) Positions selected by men and women in trials 10th to 14th. Boxes are colored according to the percentage of visits. For one reward condition only the first selected position is represented. For three rewards condition the first three selections are represented for each participant. Rewarded boxes were marked with an oblique line; B) Caption about percentage of visits; C) Schema about the room orientation and cues available.

Acquisition (Trials 1 to 10): A two-way ANOVA (Gender x Trial, with repeated measures in the last variable) revealed significant differences in factor Trial $F(9,216) = 23.8$, $p = 0.0001$. No differences were found in factor Gender $F(1,24) = 0.61$, $p = 0.44$ or Gender x Trial interaction $F(9,216) = 0.87$, $p = 0.545$. Post-hoc analysis of Trial revealed that the asymptotic level was reached on trial 3 ($p < 0.05$). Participants made more errors on trials 1 and 2 in comparison with the rest of trials (Figure 2).

Finally, an analysis of trials 10, 11, 12, 13 and 14 was run. An ANOVA (Gender x Trial, with repeated measures in the last variable) disclosed significant differences in Trial $F(4,96) = 55.95$, $p = 0.000$ but no significant differences were found in Gender $F(1,24) = 0.09$, $p = 0.76$ nor significant Gender x Trial interaction $F(4,96) = 0.52$, $p = 0.717$ (Figure 2). Post-hoc analysis of Trial revealed that participants made more errors on trial 11, when the box location was moved to another position. From trials 12 to 14 there were no differences with trial 10. That is, after changing box location participants required only one trial to reach the asymptotic level of performance (mean of errors in trial 10 = 0.26; mean in trial 11 = 7.5; mean in trial 12 = 1.26; mean in trial 13 = 0.96; mean in trial 14 = 0.42) (Figure 2).

Latency: ANOVA (Gender x Trial, with repeated measures in the last variable) of the latencies during trials 1 to 10 showed significant differences in Trial factor $F(9,216) = 38.41$, $p = 0.0001$ and no differences in Gender $F(1,24) = 1.75$, $p = 0.197$. There was not a significant main effect of Gender x Trial interaction $F(9,216) = 0.97$, $p = 0.463$. Post-hoc analysis of Trial revealed that asymptotic level was reached on trial 3 ($p < 0.001$). Trials 1 and 2 showed differences with the rest of trials (Figure 3).

Analysis of trials 10 to 14 with a two-way ANOVA (Gender x Trial, with repeated measures in the last variable) revealed a significant main effect of Trial $F(4,96) = 45.57$, $p = 0.000$. There were not differences in Gender factor $F(1,24) = 1.16$, $p = 0.291$or in the interaction term Gender x Trial $F(2,96) = 1.57$, $p = 0.188$ (Figure 3).

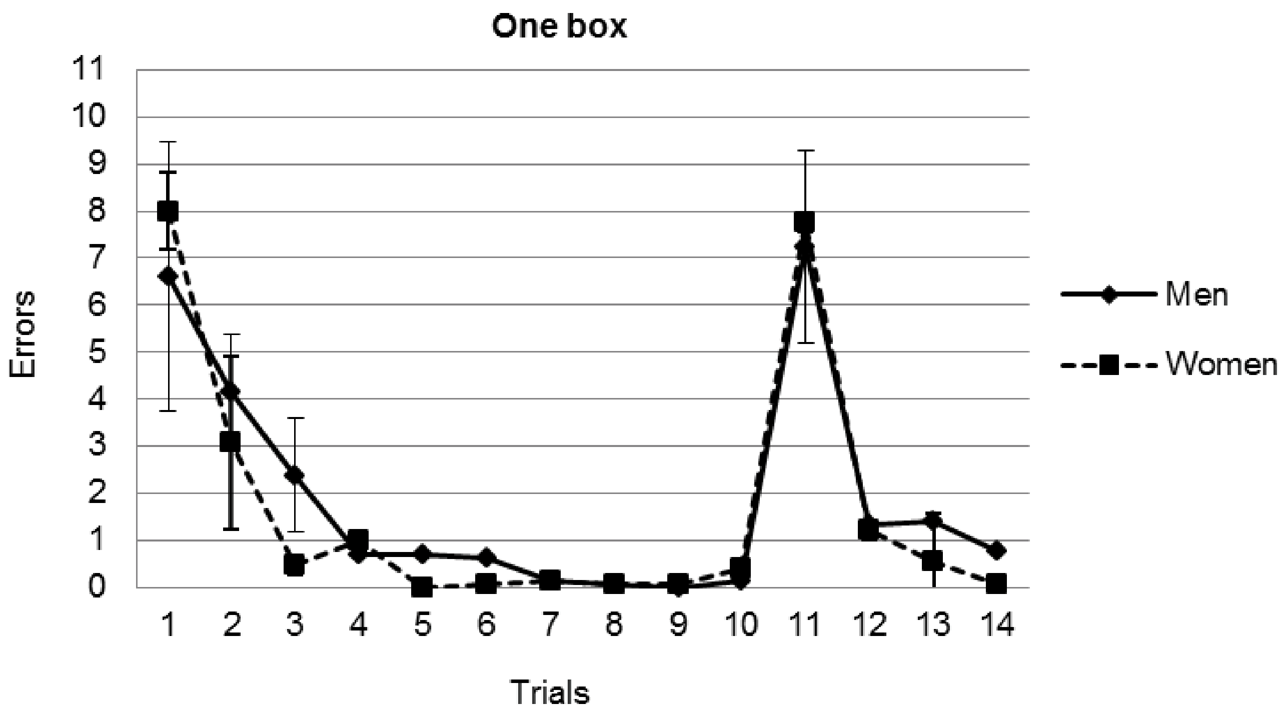

Figure 2: Number of errors committed by men and women in the one reward condition. The asymptotic level was reached in the 3rd trial. The location of the rewarded box was changed in trial 11. Participants reached the asymptotic in trial 12. Mean ± SEM.

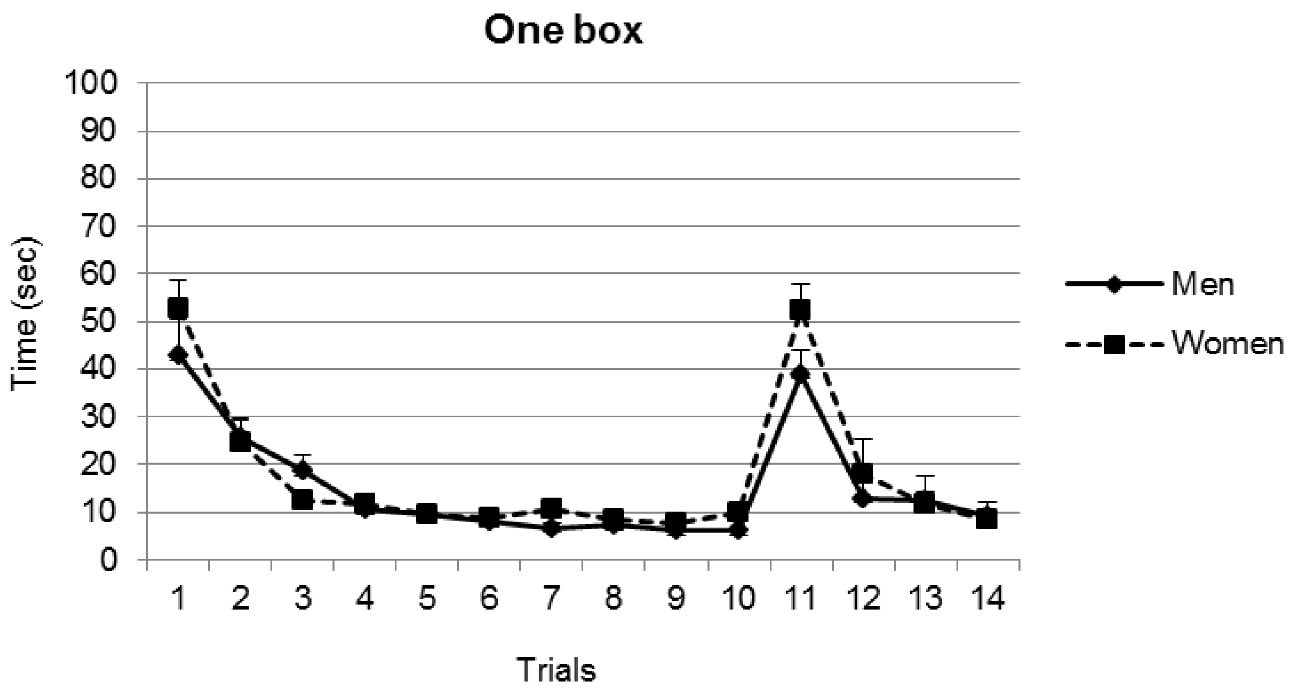

Figure 3: Time spent by men and women in one reward condition. The asymptotic level was reached in the 3rd trial. The location of the rewarded box was changed in trial 11. Afterwards, the asymptotic level was reached in trial 12. Mean ± SEM.

Post-hoc analysis of Trial showed that after changing the target position the asymptotic level was reached in the second trial. There were not significant differences between trials 10 and trials 12, 13 and 14 (mean of seconds in trial 10 = 8.15; mean in trial 11 = 45.69; mean in trial 12 = 15.57; mean in trial 13 = 12.11; and mean in trial 14 = 8.8) (Figure 3).

Three rewarded boxes

Errors

Acquisition (Trials 1 to 10): A two-way ANOVA (Gender x Trial, with repeated measures in the last variable) revealed significant differences in the factor Trial $F(9,2889) = 59.99$, $p = 0.000$ but not in Gender $F(1,31) =$

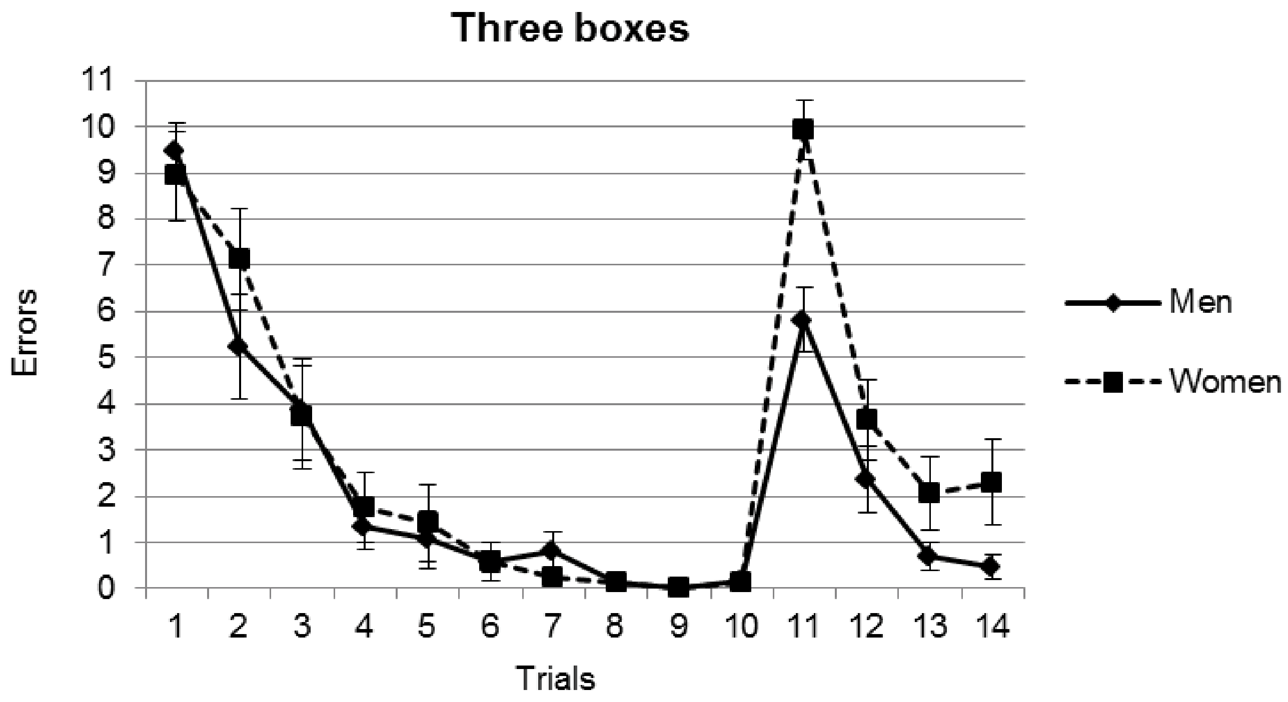

Figure 4: Number of errors committed by men and women in the three rewards condition. The asymptotic level was reached in trial 4. The location of the rewarded boxes was changed in trial 11, where men outperformed women. After changing the location the asymptotic level was reached in the 3rd trial (trial 13). Mean ± SEM.

0.03, $p = 0.775$. The interaction Gender x Trial was not significant $F(9,288) = 0.74$, $p = 0.669$. Post-hoc analysis revealed that the asymptotic level was reached on the 4th trial ($p < 0.05$) (Figure 4).

A two way ANOVA (Gender x Trial, with repeated measures in the last variable) to number of errors on trials 10 to 14 disclosed significant differences on the factor Trial $F(4,128) = 65.44$, $p = 0.000$ and Gender $F(1,32) = 10.25$ $p = 0.003$. Gender x Trial interaction was also significant $F(4,128) = 4.09$, $p = 0.003$. Post-hoc analysis of Gender x Trial revealed that men committed less errors than women on trial 11 (mean of men = 5.82; mean of women = 9.94). In addition, both men and women reached the asymptotic level on trial 13, that is, in the 3rd trial after changing target position (Figure 4).

Latency: ANOVA (Gender x Trial, with repeated measures in the last variable) to latencies on trials 1 to 10 revealed differences in Trial factor $F(9,288) = 46.46$, $p = 0.0001$. No significant differences emerged in Gender factor $F(1,32) = 0.88$, $p = 0.353$ or in Gender x Trial interaction $F(9,288) = 1.37$, $p = 0.197$. Post-hoc analysis of Trial confirmed that the asymptotic level was reached in trial 5 ($p < 0.05$). Participants spent more time on completing trials 1st to 4th than in the rest of trials (Figure 5).

Finally, analyses of latencies in trials 10 to 14 revealed statistical differences in the factors Trial $F(4,128) = 59.4$, $p = 0.000$ and Gender $F(1,32) = 8.44$, $p = 0.006$. There were not significant main effect in the interaction term Gender x Trial $F(4,128) = 2.06$, $p = 0.089$.

Post-hoc analysis of Trial revealed that participants spent more time in trial 11 (mean = 71.85 seconds) in comparison with the rest of trials. Also trial 10 participants took less time (mean = 16.14) than in trials 12 (mean = 35.38 seconds) and 13 (mean = 22.73 seconds). Trial 14 (mean = 23.14 seconds) did not differ from trial 10 (mean = 16.14 seconds). Regarding gender, men spent less time than women to complete the reversal task (mean of men = 26.81 seconds; mean of women = 40.89 seconds) (Figure 1 and Figure 5).

Discussion

This study shows that men and women differed in their performance during the reversal training in a spatial memory task. Groups did not differ during acquisition, achieving a good level of performance in both conditions of difficulty. Searching for one rewarded position, they reached the asymptotic level on the 3rd trial. Few more trials were needed to reach the asymptotic level when searching for three targets.

Our results are in line with other works where dimorphism appeared at specific difficulty levels. If demands are very low or high, both genders showed a similar performance. However, male participants outperformed their female counterparts at intermediate difficulty levels [30,32,33,35]. Specifically, the Boxes Room task used by Cánovas, et al. (2008) [33] and Cánovas & Cimadevilla (2011) [30] disclosed gender differences when five locations had to be remembered. In a similar spatial recognition task, Tascón, García-Moreno & Cimadevilla (2017) [36] showed that men and women differed when two or three positions had to be remembered but differences disappeared when remembering one position.

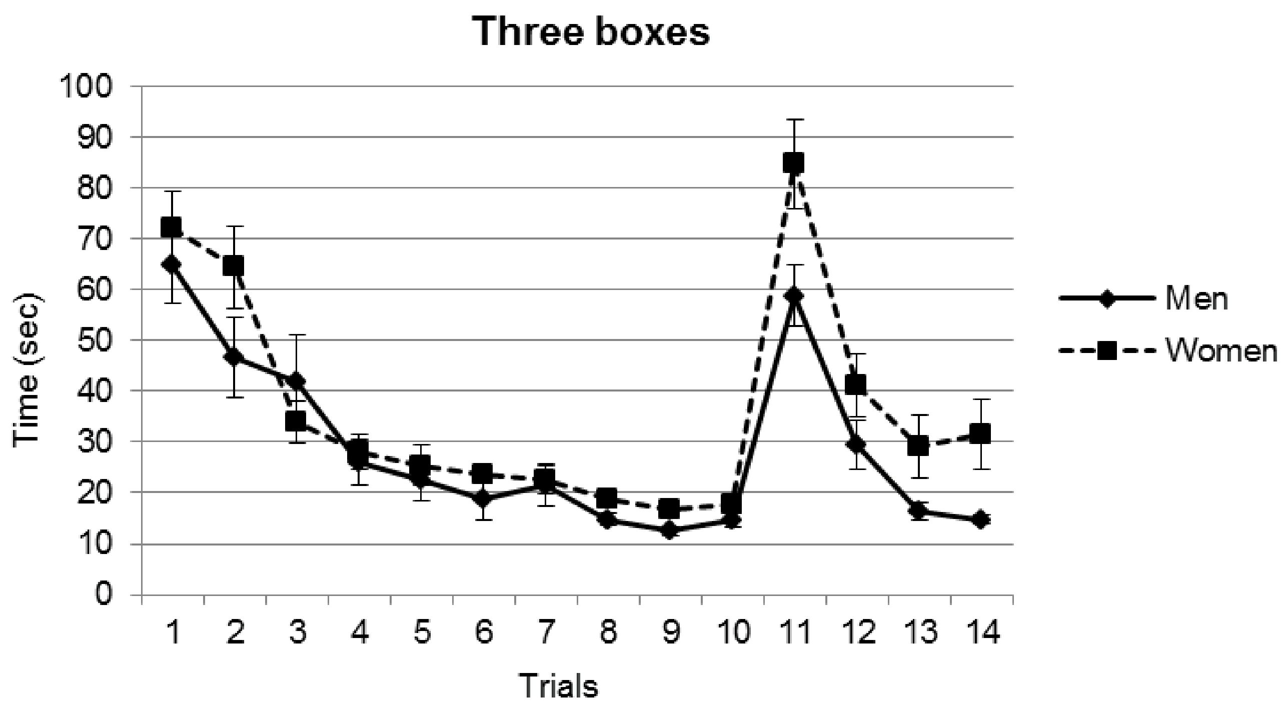

Figure 5: Time spent by men and women in the three rewards condition. The location of the rewarded boxes was moved in trial 11. Men spent shorter time than women after changing the target. Mean ± SEM.

This study also proves that acquisition was similar in both groups and both conditions. Figure 1A represents positions selected by men and women from trial 10th to 14th. In both difficulty conditions men and women selected in almost the 100% of the cases the correct positions in trial 10th, showing that they achieved a good accuracy before the reversal phase. In trial 11th the rewarded boxes were moved to a new position. However, participants visited the previous rewarded positions. Trials from 12th to 14th showed the new learning. Reversal training disclosed dimorphism since women were slower than men searching for three boxes. It is possible to note that women did not reach the 91% of visits in any of the right positions. This means that men and women showed different capabilities of adaptation to this new situation. Women also committed more errors than men in trial 11th, although performance is considered to be random since the new positions were moved to other locations. It is important to stress that reversal condition seems to be more discriminative than the initial learning in spatial tasks [13]. These results are also in consonance with other studies that measured reversal learning in non-spatial tasks [10,29,37-39]. As in the current study, men and women reached a similar level of performance until the reversal phase, when gender dimorphism appeared.

Several explanations could account for this gender-specific behavior. Thus, dimorphism could be due to a different flexibility, with women persisting in previous targets. However when compared, women did not visit more than men old rewarded positions.

In our test women developed a tendency to visit a larger number of positions than men did, who, in turn, were more selective in their decisions. Thus, whereas in the three reward condition men chose a total of four different boxes in trial 14th, women spread their search to seven different locations. This can explain differences in latency and could demonstrate that the spatial representation of the environment was more accurate in men. Therefore, gender differences cannot be explained in terms of cognitive flexibility.

On the other hand, dimorphism could emerged by the differential ability in imagery skills. Mental imagery is crucial to orientate through the space [40,41]. In each trial participants begin their task from a different wall in the room, so they needed to update the information about landmarks and locations relationships. Abilities to form a cognitive map and to do mental rotation are helpful to achieve the task demands. So, differences could have emerged because men are better than women in mental rotation as well as in making up cognitive maps [18,20-23] which help them to reorganize the information when target locations are moved. However, as shown before, both groups did not differ in the learning phase, and in this respect, this hypothesis is likely to have a minor role. Notwithstanding, it should be borne in mind that these different abilities may have an impact on the chosen strategies when it comes to resolve the task. Regarding this, Goldberg (1994) [42] reported in the Cognitive Bias Task that men were prone to use dependence context strategies whereas women preferred independent context strategies. On similar lines, it was demonstrated that women usually use landmark or route strategies, whereas men chose survey strategies, related with metric and allocentric information and the capacity to create mental maps [18,22,31]. Geometrical is more adequate than landmark information since information about distances and spatial relationships was omitted in the latter ones [43,44]. This could be the reason why women had a tendency to be more disperse than men after the change of the spatial location was produced (Figure 1A). It is interesting to highlight that there were not landmarks on the North wall (Figure 1C). Accordingly, women could not rely on any cue for orientation and they made more mistakes when they opened the boxes which were close to this wall.

It is worthy to note also the differential use of strategies in non-spatial tasks. Thus, whereas men are prone to operate with global information, women work with more detailed data [27-29], affecting performance in decision making tasks [29].

Finally, another factor that could contribute to differences observed is the working memory load. Searching for three positions makes the task more complicated since participants need to remember more locations. In our study the reversal phase demanded a greater working memory load. Participants were forced to maintain not only the previous locations to inhibit them, but also the new ones to be selected. This could be the reason that explains why dimorphism did not appear in the acquisition phase but in the new learning. This explanation is supported by other studies reporting sexual dimorphism in tasks with high visuo-patial working memory load where participants had to elaborate, integrate and transform the visual imagined material. Differences decrease when the working memory load is reduced [31,33,45,46].

This study showed that reversal protocol challenges spatial memory abilities even in conditions accurately learned by participants. The dimorphism described cannot be explained as a lack of flexibility or inhibition but as other processes involved like better strategies used by men or their higher spatial working memory capacity.

Conflict of Interest Statement

No potential conflict of interest is declared by the authors.

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