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Male advantage in geometry learning? A preliminary study in rats

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Psicología Comparada y Cognición Animal

Abstract

Rats were successively trained in three unusual watermazes to find a hidden platform that always maintained a constant relationship with a distinctive corner of the apparatus (i.e., a triangular-shaped pool in Experiment 1, a rectangular-shaped pool in Experiment 2, and a kite-shaped pool in Experiment 3). After each training phase a test trial was conducted, without the platform. On test, in Experiment 1 the amount of time the rat spent in two different areas, one in front of the correct corner and one in exactly an opposite and incorrect corner was recorded. The experiment replicated previous results: a clear male advantage on geometry learning (Rodríguez et al., 2010, 2011). Additional measures were also employed in Experiments 2 and 3 and, in both experiments, the different measures of spatial learning gave quite different results. The male advantage found in Experiment 1 did not seem to generalize well to other geometries.

Key Words:
Geometry Learning; Sex Differences; Watermaze; Rats.

Resumen

¿Superioridad de los machos en el aprendizaje de la geometría? Un estudio preliminar con ratas: Se entrenó a ratas de forma sucesiva en tres inusuales laberintos acuáticos a encontrar una plataforma oculta que mantenía una relación constante con una esquina distintiva del aparato (i.e., piscina triangular, rectangular y con forma de cometa en los Experimentos 1-3, respectivamente). Tras cada fase de entrenamiento se llevó a cabo un ensayo de prueba, sin plataforma. En la prueba, en el Experimento 1 se registró el tiempo que pasaban las ratas en dos áreas diferentes, una frente a la esquina correcta y otra en la esquina opuesta e incorrecta. Este experimento replicó resultados anteriores: se encontró una clara superioridad de los machos en el aprendizaje de la geometría (Rodríguez y cols, 2010, 2011). En los Experimentos 2 y 3 se utilizaron medidas adicionales y, en ambos experimentos, las distintas medidas de aprendizaje espacial dieron resultados significativamente diferentes. La superioridad de los machos encontrada en el Experimento 1 no parece generalizarse bien a otras geometrías.

Palabras Claves:
Aprendizaje de la Geometría; Diferencias de Sexo; Laberinto Acuático; Ratas.

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1. Introduction

Cheng (1986) was the first author to present evidence that rats can use geometric information to locate a hidden goal. He trained male rats in a rectangular arena, where the two short walls of the box and one of the long walls were black, while the other long wall was white. In addition, distinctive visual patterns were placed in each of the box's corners (as well as other non-geometric cues). Food was buried in one corner of the box, and the rats had to search for it. Although rats learned to search in the correct location for the food, they made frequent rotational errors searching in the corner diagonally across from the one where the food was hidden. The only characteristic that the target corner and the corner diagonal from it shared in common was having one long wall to the left and one short wall to the right, which implies that the information provided by the non-geometric sources of information to find the food location did not seem to be important. Cheng concluded that the rats used the geometric framework of the box itself (see also Gallistel, 1990). Similar results have been found not only with rats but also with other species (for reviews see Cheng & Newcombe, 2005; Tommasi, Chiandetti, Pecchia, Sovrano, & Vallortigara, 2012).

According to Cheng (1986) and Gallistel (1990), learning about geometric information (i.e., like the

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metric relations of distances and angles between a target place and the shape of an apparatus) occurs in a specialized module, which is impenetrable to non-geometric information (although see Cheng, 2008). Features such as landmarks are considered to be related to this featureless metric frame by means of address labels (see Cheng, 1986, p. 172). Two main predictions should be considered in this controversial topic. If geometry and landmark learning represent quite independent modes of solution (Cheng, 1986; Gallistel, 1990), one might not expect to see any interaction or competition between them. Consequently, no evidence of cue competition effects (like blocking and overshadowing) should be found between geometric and non-geometric information. However, Miller and Shettleworth (2007) have claimed that changes in the associative properties of the geometric cues are governed by the same principles that apply to more traditional stimuli. Consequently, one might expect to see interactions or competition between geometric and non-geometric information. Different authors have confirmed the two outcomes (for a review see Pearce, 2009). Not yet reached an agreement.

Importantly, neither Cheng nor any of the studies reviewed by Pearce (2009) have examined sex differences when using rats. What would have happened if the rats in Cheng's study (1986 –as well as those in the other studies) had been females? Two recent papers (Rodríguez, Chamizo, & Mackintosh, 2011; Rodríguez, Torres, Mackintosh, & Chamizo, 2010) have addressed this issue. In the study by Rodríguez et al. (2010, Experiment 2) rats were trained in a triangular-shaped pool to find a hidden platform, whose location was defined in terms of two sources of information: one landmark next to the platform, but outside the pool, and one particular corner of the pool. After training, a test trial without the platform pitted these two sources of information against one another. The results revealed that females spent more time in an area of the pool next to the landmark, while males spent more time in the corner of the pool where the platform had originally been located. Moreover, additional test trials showed that when the two sources of information were presented in isolation, although both sexes had learned about the two cues, males and females had equally learned about the landmark cue, but males outperformed females in geometry learning. Overall, these results imply that the geometrical cue is more salient for males, while the landmark cue is more salient for females. The subsequent study by Rodríguez et al. (2011), where cue competition designs were used, confirmed this claim by showing that overshadowing is asymmetrical, both in males and in females. In males, geometry learning overshadows landmark learning, but not vice-versa; while in females, landmark learning overshadows geometry learning, but not vice-versa. Moreover, these effects were not influenced by the females' estrus cycle.

Although the study by Rodríguez et al. (2011) clearly shows that geometry is more salient for males while the landmark cue is more salient for females (which is consistent both with the rodent and the human literature –see Kimura, 1999), subsequent work in our laboratory (unpublished pilot data) have found that when using a different shaped-pool the results were not so clear. Does the males' superiority in geometry learning disappear depending on the specific shaped-pool used? The present study constitutes our first work to answer this question. We present three experiments, conducted with the same rats, using the triangular-shaped pool employed in the previous studies by Rodríguez et al. (Experiment 1), a rectangular-shaped pool (Experiment 2), and a kite-shaped pool (Experiment 3), to investigate the hypothetical male superiority when geometry learning.

An alpha level of .05 was adopted for all the statistical analyses and the program used was SPSS.

Experiment 1

Experiment 1 was conducted with male and female rats using the same shaped-pool, procedure, and measures as those employed in the study by Rodríguez et al. (2010, Experiment 2), with the important exception that the landmark cue was removed (see Figure 1, top panel). Therefore, in this experiment, the animals had only the information provided by the geometrical cue to locate the position of the platform. No other cue could neither overshadow nor potentiate such learning. Under these conditions, would males outperform females?

2. Method

2.1. Subjects

The subjects were naive Long Evans rats from our own colony: 12 males and 12 females, approximately three months old at the beginning of the experiment. The animals were housed in standard cages, 25 x 15 x 50 cm, in groups of two and were maintained on ad lib food and water, in a colony room with a 12:12-hr light-dark cycle. They were tested within the first 8 hrs of the light cycle.

2.2. Apparatus

The apparatus was a circular swimming pool made of plastic and fibreglass and modelled after that used by Morris (1981). It measured 1.58 m in diameter and 0.65 m deep, and it was filled to a depth of 0.49 m with water rendered opaque by the addition of 1 cl/l of latex. The water temperature was maintained at 22 + 1°C. The pool was situated in the middle of a large room and mounted on a wooden platform 0.43 m above the floor. To create the triangular shape, two acrylic boards forming an angle of 90º were inserted in the pool resting on platforms at the base, which supported them vertically. The boards were 39.5 cm high, 0.5 cm thick and 112 cm long. The top of the boards was 9.5 cm above the water surface, i.e., at the same height as the outer wall of the pool. The pool was surrounded by black curtains reaching from the ceiling to the base of the pool and forming a circular enclosure 2.4 m in diameter. In order to ensure that the rats used the information provided by the geometry of the pool to locate the platform, rather than any inadvertently remaining static room cues (like noises from pipes and air conditioning), the two boards and the platform were semi-randomly rotated with respect to the room (90°, 180°, 270°, or 360°) with the restriction that all four positions of the room were used each day. A closed-circuit video camera with a wide-angle lens was mounted 1.75 m above the centre of the pool inside the false ceiling, and its picture was relayed to recording equipment (by means of a Smart 3.0, video tracking system –Panlab, Harvard Apparatus) in an adjacent room. A circular platform 0.11 m in diameter and made of transparent Perspex was mounted on a rod and base which was placed 0.38 m from the point formed by the corner of the pool with a straight wall to the left, and the circular base of the triangle to the right, on a line that bisected the centre of the pool, with its top 1-cm below the surface of the water. The hidden platform, P, and the geometry of the pool were situated as shown in Figure 1, top panel.

2.3. Procedure

There were three types of trials: pretraining and training (both of them escape trials), and test trials. Pretraining consisted of placing a rat into the circular pool without the landmark or boards, but with the hidden platform present. The rat was given 120 s to find the platform, and once the rat had found it, it was allowed to stay on it for 30 s. If it had not found the platform within the 120 s, it was picked up, placed on it, and left there for 30 s. The platform was moved from one trial to the next, and the rat was placed in the pool in a different location on each trial, as far as possible equally often on the same or opposite side of the pool from the platform, and with the platform to the right or to the left of where the rat was placed. Rats were given five such pretraining trials over two days, with two trials on Day 1, and three on Day 2. Rats were run in groups of ten and spent the intertrial interval (ITI) in small individual compartments.

The procedure for training was similar to that of pretraining with the exception that the two boards forming the triangular shaped pool, as shown in Figure 1, top panel. As in pretraining, the rat was placed in the pool in a different location on each trial, as far as possible equally often with the platform to the right, to the left or in front of where the rat was placed (at I, II, and III of the previous figure). Rats were given eight trials per day over five days (a total of 40 trials). These trials had an ITI of 8-10 min, and the platform, landmark, and triangular shape were rotated between trials.

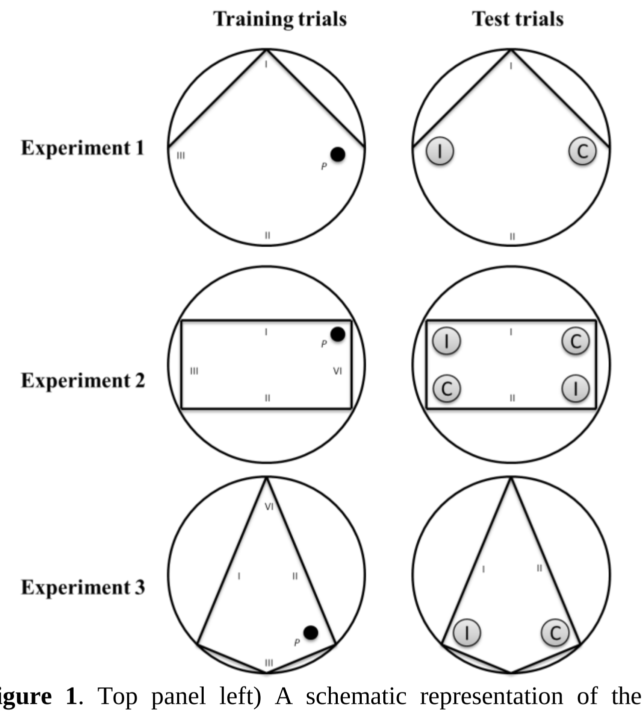

Figure 1. Top panel left) A schematic representation of the triangular pool as well as the position of the hidden platform (P), and the starting positions (I, II, III) used in the training trials of Experiment 1. Top panel right) A schematic representation of the triangular pool, as well as the two recording areas (correct and incorrect), and the starting positions (I, II) used in the test trial of Experiment 1. Middle panel left) A schematic representation of the rectangular pool, as well as the position of the hidden

platform (P) and the starting positions (I, II, III, IV) used in the training trials of Experiment 2. Middle panel right) A schematic representation of the rectangular pool, as well as the four recording areas (two correct and two incorrect) and the starting positions (I, II) used in the test trial of Experiment 2. Bottom panel left) A schematic representation of the kite shaped pool, as well as the position of the hidden platform (P) and the starting positions (I, II, III, IV) used in the training trials of Experiment 3. Bottom panel right) A schematic representation of the kite shaped pool, as well as the two recording areas (correct and incorrect), and the starting positions (I, II) used in the test trial of Experiment 3.

Finally, there was a test day with eight training trials (identical to the training phase), followed by one test trial without the platform. Test trial was 60 s long. The amount of time the rat spent in two different areas (each of them 0.22 m in diameter – twice the hidden platform diameter), one in front of the correct corner (C, in Figure 1, top panel) and one in exactly the opposite corner (incorrect corner, I, in Figure 1, top panel), was recorded. Each rat was placed in the pool from one specific position (at I and II only, as shown in Figure 1, top panel).

3. *Results and Discussion*

Latencies to find the platform decreased over the course of the 5 initial pretraining trials. Males decreased from means of 44.8 s on Trial 1 to means of 35.4 s on Trial 5, and females decreased from means of 104.0 s on Trial 1 to means of 51.9 s on Trial 5. A repeated measures ANOVA conducted on these data taking into account the variables trials (1-5) and sex showed that the only significant variable was trials, $F(4,88) = 6.43$, $p < .001$. No other main effect or interaction was significant ($Fs < 2.5$). All rats improved their performance as pretraining trials progressed.

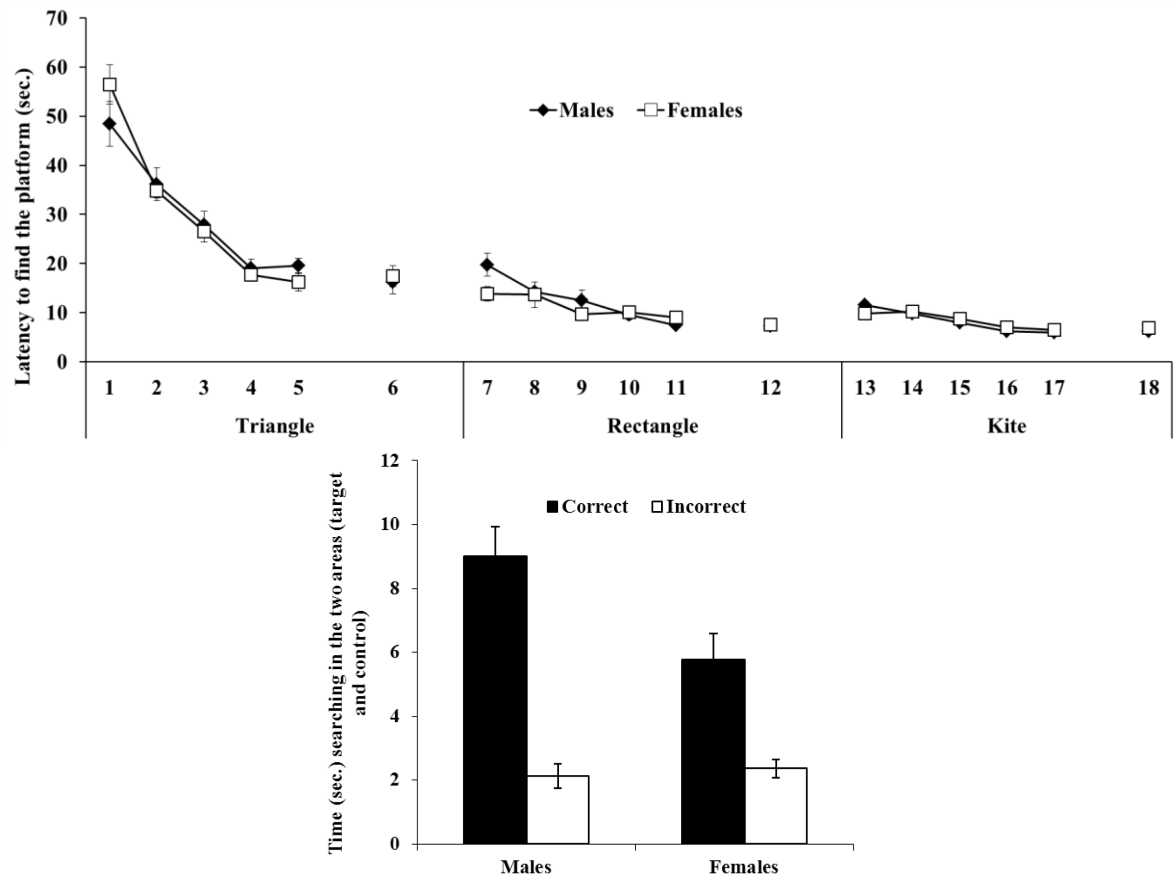

Figura 2. Top panel) Mean escape latencies by the two groups in Experiments 1-3. Error bars denote standard errors of the means. Bottom panel) Mean time spent in the two recording areas (correct and incorrect) by the subjects during the test trial of Experiment 1. Error bars denote standard error of the means.

Figure 2 (top panel, left) shows the mean escape latencies of the two sexes during both the training and the escape trials of the test day (Day 6 in Figure 2 top panel, left). A repeated measures ANOVA conducted on the training trials data, taking into account the variables sex (males, females) and days (1-5) revealed that the only significant variable was days, $F(4,88) = 80.79$, $p < .001$. No other main effect or interaction was significant ($Fs < 2.0$). A univariate ANOVA of the escape trials during the test day (day 6) revealed that males and females did not differ ($F < 0.5$).

Figure 2 (bottom panel) shows the time spent in the two recording areas (i.e., correct and incorrect) by males and females during the 60 s test trial. A repeated measures ANOVA conducted on these data, taking into account the variables area (correct, incorrect) and sex (males, females) revealed that the variables area, $F(1,22) = 96.58$, $p < .001$, and sex, $F(1,22) = 17.56$, $p < .001$, were significant, as well as the interaction area by sex, $F(1,22) = 10.87$, $p = .003$. Simple effects analysis of the interaction area x sex showed that both males and females spent more time in the correct than in the incorrect area, $F(1,22) = 67.46$, $p < .001$, and $F(1,22) = 29.49$, $p < .001$, males and females respectively. Most importantly, a sex difference on geometry learning was found: males spent more time than females in the correct area, $F(1,22) = 14.86$, $p < .001$.

Experiment 2

The results of Experiment 1 revealed that when the geometrical cue provides the only significant information to locate the position of the hidden platform, males outperform females in the triangular-shaped pool. This experiment replicates our previous results (Rodríguez et al., 2010, 2011), although with a better procedure. But, can we generalize this male advantage over females to different geometries? Experiment 2 addresses this question using a rectangular-shaped pool (see Figure 1, middle panel). Due to our lack of experience with this pool-shape, different measures were used; both during training and on test trials.

4. Method

4.1. Subjects and procedure

The same 24 subjects of Experiment 1 were used. The general procedure was the same as that in Experiment 1 for training and test trials.

4.2. Apparatus

To create the rectangular shape, four acrylic boards forming a rectangle were inserted in the pool resting on platforms at the base, which supported them vertically. Two boards, the short ones, were 39.5 cm high, 0.5 cm thick and 58 cm long. The resting two boards, the large ones, were 39.5 cm high, 0.5 cm thick and 145 cm long. The top of the boards was 9.5 cm above the water surface, i.e., at the same height as the outer wall of the pool. The experimental room and the platform were the same as those used in Experiment 1. To allow the new measures described below, in this experiment (and also in Experiment 3) the pool corners were avoided as starting points.

To understand the measures in the rectangular-shaped pool some explanation is needed. The hidden platform is located in one of the four corners of the pool only (see Figure 1, middle panel, left). The correct location is defined as having a short wall to the right and a long wall to the left. Two of the four corners correspond to this description, they are geometrically identical. These two corners are considered the ‘correct area’ (C). The remaining two corners, also geometrically identical, are defined as having a long wall to the right and a short wall to the left. These two corners are considered the ‘incorrect area’ (I). Therefore, in this apparatus (like in Cheng’s, 1986) it is not possible to differentiate between the two correct corners, and between the two incorrect corners (C, C and I, I respectively in Figure 1, middle panel, right). Moreover, on test trials, the spatial linking corridor between the two correct corners (C,C) can be also considered as ‘correct area’ and the spatial linking corridor between the two incorrect corners (I, I), as ‘incorrect area’. On training trials, in addition to the latency to reach the platform, the first area (either correct or incorrect) visited by the animals was recorded. On test trials, in addition to the time searching for the platform in the two areas (correct and incorrect), the first area (either correct or incorrect) visited by the animals (i.e., the first choice) was also recorded, as well as the time spent in the two corridors (i.e., the corridor linking the two correct corners, and the corridor linking the two incorrect corners). We believe that this final new measure on test trials was necessary because it captures the “directionality” of the rats’ performance when searching for the platform better than any of the previous tests’ measures.

4.3. Results and Discussion

Figure 2 (top panel, middle) shows the mean escape latencies of the two sexes during both the training and the escape trials of the test day (Day 12 in Figure 2, top panel). A repeated measures ANOVA conducted on the training trials data, taking into account the variables sex (males, females) and days (1-5) revealed that the only significant variable was days, $F(4,88) = 10.94$, $p < .001$. No other main effect or interaction was significant ($Fs < 2.5$). A univariate ANOVA of the escape trials during the test day revealed that males and females did not differ ($F < 0.5$).

Figure 3 (top panel) shows the mean percentages of correct choices for the two sexes during both the training trials and the escape trials of the test day. A repeated measures ANOVA conducted on these data taking into account the variables days (1-5) and sex (males, females) revealed that the variable days, $F(4,88) = 18.58$, $p < .001$, was significant, as well as the interaction days x sex, $F(4,88) = 11.30$, $p < .001$. No other main effect or interaction was significant ($Fs < 4.0$). Simple effects analysis of the interaction days x sex revealed that females made more correct choices than males on Day 1, $F(1,22) = 13.67$, $p = .001$, while males made more correct choices on Days 2 and 3, $F(1,22) = 8.80$, $p = .007$, and $F(1,22) = 16.85$, $p < .001$, respectively.

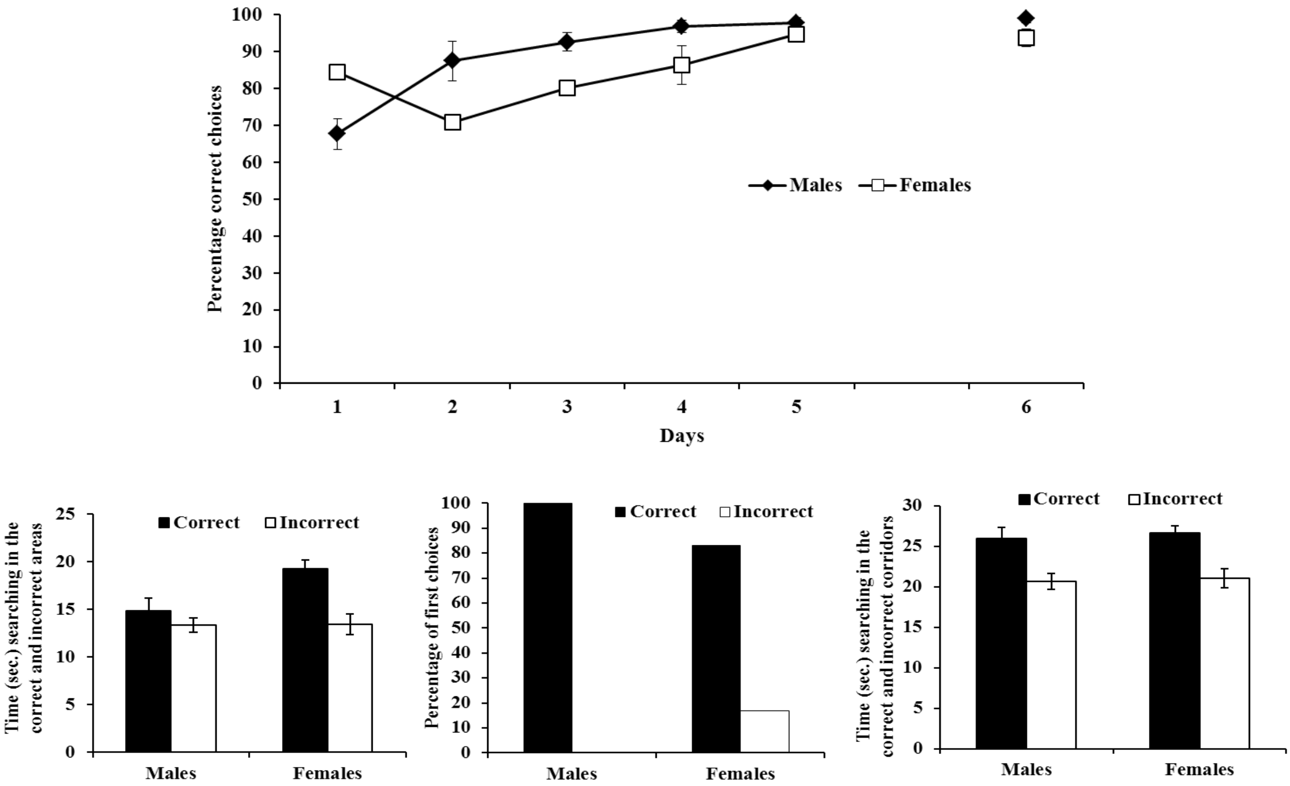

Figure 3. Top panel) Mean percentages of correct choices for the two sexes during both the training trials and the escape trials of the test day of Experiment 2. Error bars denote standard error of the means. Bottom panel left) Mean time spent in the four recording areas (i.e., two geometrically correct areas and two geometrically incorrect areas) by the subjects during the test trial of Experiment 2. Error bars denote standard error of the means. Bottom panel middle) Mean percentage of correct and incorrect choices made by the subjects during the test trial of Experiment 2. Bottom panel right) Mean time spent in the two corridors (i.e., correct and incorrect) by the subjects during the test trial of Experiment 2. Error bars denote standard error of the means.

Figure 3 (bottom panel, left) shows the time spent in the four recording areas (i.e., two geometrically correct areas and two geometrically incorrect areas – C and I, respectively, in Figure 1, middle panel) by males and females during the 60s test trial. A repeated measures ANOVA conducted on these data, taking into account the variables area (correct, incorrect) and sex (males, females) revealed that the variable area, $F(1,22) = 33.80$, $p < .001$, as well as the interaction area x sex, $F(1,22) = 11.48$, $p = .003$, were significant. Simple effects analysis of the interaction area x sex showed that only female rats spent more time in the correct than in the incorrect areas, $F(1,11) = 46.53$, $p < .001$. In addition, females spent more time than males in the correct areas, $F(1,22) = 16.02$, $p = .001$. Male rats spent the same time searching in both the correct and the incorrect areas (*F* < 3.0).

Figure 3 (bottom panel, middle) shows the mean percentages of correct and incorrect choices for the two groups during the test trial. To compare the performance of the two groups, a chi square test was conducted taking into account the variable sex and the number of trials on which a correct or an incorrect choice was made in the test trial. This test revealed that males and females did not differ in the number of correct choices, $\chi^2(1, n = 24) = 2.18$, $p = .140$, although a tendency can visually be observed.

Finally, Figure 3 (bottom panel, right) shows the time spent in the two corridors (i.e., correct and incorrect) by males and females during the 60s test trial. A repeated measures ANOVA conducted on these data, taking into account the variables corridor (correct, incorrect) and sex (males, females) revealed that the only significant variable was corridor, $F(1,22) = 25.16$, $p < .001$. No other main effect or interaction was significant (*Fs* < 0.5).

Experiment 3

The results of Experiment 2 revealed that the clear male advantage when geometry learning was based on the triangular-shaped pool found in Experiment 1 was not maintained when the pool had a rectangular shape. In addition, depending on the measure used, Experiment 2 revealed that the male advantage found in Experiment 1 could be even reversed in favour of females. It is true that the rectangular geometry has very special characteristics (mainly, two correct and two incorrect corners, instead of one correct and one incorrect corner only as in Experiment 1) that differ markedly from the triangular geometry used in Experiment 1. These differences could, somehow, affect both the rats' learning and performance. In Experiment 3 a kite-shaped pool was used (see Figure 1, bottom panel). Because the target corners (correct and incorrect alternatives) had been already present in the rectangular-shaped pool (Experiment 2), half of the animals in each sex had the corner defined by a short wall to the right and a long wall to the left as the correct alternative, and the other fifty per cent of the rats in each sex had the corner defined by a long wall to the right and a short wall to the left as the correct alternative (thus, Figure 1, bottom panel, shows the pool corresponding to half the animals only). Would males outperform females like in the triangular-shaped pool? As in Experiment 2, due to our lack of experience with this pool-shape, different measures were used; both during training and on test trials.

5. Method

5.1. Subjects and procedure

The same 24 subjects of Experiment 1 were used. The general procedure was the same as that in Experiments 1 and 2, for training and test trials.

5.2. Apparatus

In Experiment 3 a kite-shaped pool was used (see Figure 1, bottom panel). To create the kite shape, four acrylic boards were inserted in the pool resting on platforms at the base, which supported them vertically. Two boards, the short ones, were 39.5 cm high, 0.5 cm thick and 58 cm long. The resting two boards, the large ones, were 39.5 cm high, 0.5 cm thick and 145 cm long. The top of the boards was 9.5 cm above the water surface, i.e., at the same height as the outer wall of the pool. The experimental room and the platform were the same as those used in Experiments 1 and 2.

5.3. Results and Discussion

Figure 2 (top panel, right) shows the mean escape latencies of the two sexes during both the training trials and the escape trials of the test day (Day 18 in Figure 2, top panel, right). A repeated measures ANOVA conducted on the training trials data, taking into account the variables sex (males, females) and days (1-5) revealed that the only significant variable was days, $F(4,88) = 38.72$, $p < .001$. No other main effect or interaction was significant (*Fs* < 3.0). A univariate ANOVA of the escape trials during the test day revealed that males and females did not differ (*F* < 2.0).

Figure 4 (top panel) shows the mean percentages of correct choices for the two groups during both the training trials and the escape trials of the test day. A repeated measures ANOVA conducted on these data taking into account the variables days (1-5) and sex (males, females) revealed that the only significant variable was days, $F(4,88) = 24.08$, $p < .001$. No other main effect or interaction was significant (*Fs* < 0.5).

Figure 4 (bottom panel, left) shows the time spent in the two recording areas (i.e., correct and incorrect) by males and females during the 60s test trial. A repeated measures ANOVA conducted on these data, taking into account the variables area (correct, incorrect) and sex (males, females) revealed that the only significant variable was area, $F(1,22) = 67.26$, $p < .001$, indicating that both males and females spent more time in the correct than in the incorrect area.

Finally, Figure 4 (bottom panel, right) shows the mean percentages of correct and incorrect choices for the two groups during the test trial. To compare the performance of the two groups, a chi square test was conducted taking into account the variable sex and the number of trials on which a correct or an incorrect choice was made in the test trial. This test revealed that males and females did not differ in the number of correct choices, $\chi^2(1, \ n = 24) = 0.686$, $p = .408$, although a tendency can visually be observed.

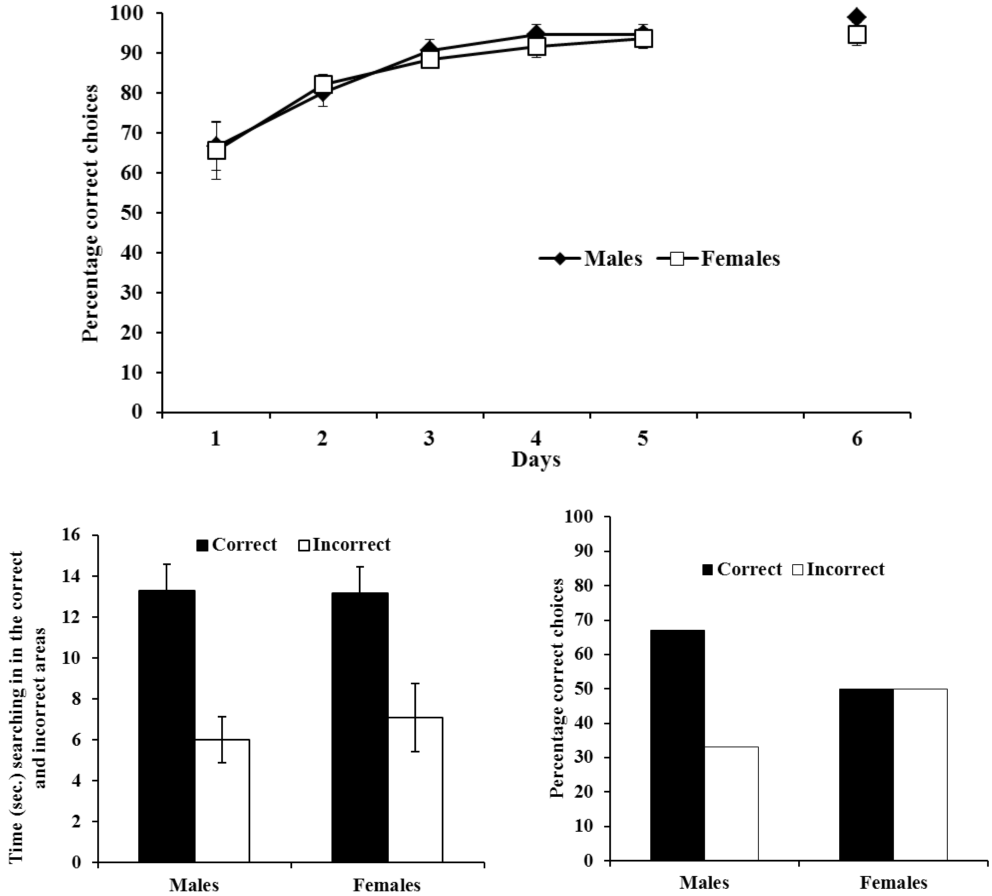

Figure 4. Top panel) Mean percentages of correct choices for the two sexes during both the training trials and the escape trials of the test day of Experiment 3. Error bars denote standard error of the means. Bottom panel left) Mean time spent in the two recording areas (correct and incorrect) by the subjects during the test trial of Experiment3. Error bars denote standard error of the means. Bottom panel right) Mean percentage of correct and incorrect choices made by the subjects during the test trial of Experiment 3.

6. General Discussion

In Experiment 1, male and female rats were trained to find a hidden platform located in one corner of a triangular-shaped pool. All rats improved their performance over the course of training and males and females did not differ. The, a subsequent test trial without the platform revealed that males spent more time than females in the correct area of the pool, thus replicating previous results by Rodríguez et al. (2010, 2011), showing that males outperform females when geometry learning. In Experiment 2, the same rats were trained to find a hidden platform located in one particular corner of a rectangular-shaped pool and the test results of Experiment 1 were not replicated. Now female rats spent more time in the two corners of the correct area than males (which did not differ between the time spent in the correct and in the incorrect areas). Moreover, the remaining two measures registered on the test trial of Experiment 2 did not replicate such female advantage in geometry learning: A male advantage was suggested when measuring first choice (i.e., correct vs. incorrect areas), and no sex differences were found when measuring time searching in the correct corridor (a new measure that captures directionality while swimming). In addition, the results of the escape trials during the acquisition phase were also surprising in Experiment 2. No sex differences were found when latency to reach the platform was measured; however, these latencies were unexpectedly good on days 1 and 2 somehow suggesting that the rats were “familiar” with the new shape of the pool. But as a whole, a clear tendency favouring males was obtained (with the exception of Day 1) when the first area visited by the animals was recorded. Finally, in Experiment 3 the same rats were trained, once more, to find a hidden platform located in one particular corner of a kite-shaped pool and again the test results of Experiment 1 were not replicated, although some suggestion of a male advantage when geometry learning was found when measuring first choice (i.e., correct vs. incorrect area). In addition, no sex differences were found neither when latency to find the platform was measured (as in Experiment 2, these latencies were unexpectedly good on days 1 and 2 somehow suggesting that the rats were “familiar” with the new shape of the pool), nor when measuring first choice.

In conclusion, the results of Experiments 2 and 3 suggest that the male advantage in geometry learning found in the triangular-shaped pool do not generalize well to the other two geometries: the rectangular-shaped pool and the kite-shaped pool.

Are we using correct measures in Experiments 2 and 3? We believe so because when a similar rectangular-shaped pool (Hayward, Good, & Pearce, 2004; McGregor, Hayward, Pearce, & Good, 2004) and a similar kite-shaped pool (Horne & Pearce, 2009) have been used in other studies (for a revision see Pearce, 2009), percentage of correct choices during both training trials and the first choice in the test trial have been used as measures.

Looking at Figure 2, top, it seems evident that the rats have learned something in Experiment 1 that seems to generalize well to Experiments 2 and 3. A candidate is selective attention due to the successive presentation of different pool-shapes which share corners or angles (i.e., the relevant ‘dimension’ of all the shapes). When animals are trained on two discriminations, they learn the second rapidly if the relevant stimuli are from the same dimension as the first discrimination (an intradimensional or ID shift) but slowly if the relevant stimuli for the two problems are from different dimensions (an extradimensional or ED shift). Specifically, when landmark learning, rats trained on a spatial discrimination do not learn to attend to all spatial landmarks but only to those that serve to differentiate S+ and S- (Trobalon, Miguelez, McLaren, & Mackintosh, 2003). The same selective attention could be expected when successive geometry problems are presented to the rats, being the location of the platform discovered only by reference to a corner, the relevant dimension.

Admittedly, Experiments 1 and 3 have many things in common. It could even be argued that Experiment 3 is an easier version of Experiment 1, because the two target corners are closer than in Experiment 1. If this reasoning is correct, then we should not be surprised by the absence of sex differences in Experiment 3 (for a demonstration showing that males and females learn to swim to the platform equally rapidly when a swimming problem is made easier, see Forcano, Santamaría, Mackintosh, & Chamizo, 2009). More research is certainly needed to understand geometry learning in rats. In the present study, did the animals relied on the global representation of the apparatus or alternatively, on local cues, like boundaries (Doeller & Burgess, 2008; Doeller, King, & Burgess, 2008)? Could females find difficult curved but not straight lines? Could our Experiments 2 and 3 be reflecting floor effects? Is the order of the three pools a critical variable in the present results? Future experiments will answer all the previous questions.

After the research on geometry learning begun by Cheng (1986) and successfully followed by Pearce and his colleagues (for a review see Pearce, 2009), it has been shown that female rats can also learn and use the information given by the geometric framework of an apparatus (as first suggested by Williams, Barnett, & Meck, 1990). The present results provide further evidence of such a demonstration and open new questions. Moreover, it has an important methodological message. Different measures of spatial learning or performance can give quite different results. Thus, a recommendation would be to use as many as possible so that specific conclusions would be secure.

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References

Cheng, K. (1986). A purely geometric module in the rat’s spatial representation. *Cognition*, 23, 149–178.

Cheng, K. (2008). Whither geometry? Troubles of the geometric module. *Trends in Cognitive Sciences*, 12, 355-361.

Cheng, K., & Newcombe, N. S. (2005). Is there a geometric module for spatial orientation? Squaring theory and evidence. *Psychonomic Bulletin & Review*, 12, 1-23.

Doeller, C. F., King, J. A., & Burgess, N. (2008). Parallel striatal and hippocampal systems for landmarks and boundaries in spatial memory. *Proceedings of The National Academy of Sciences of the United States of America*, 105, 5915-20.

Doeller, C. F. & Burgess, N. (2008). Distinct errorcorrecting and incidental learning of location relative to landmarks and boundaries. *Proceedings of The National Academy of Sciences of the United States of America*, 105, 5909-14.

Forcano, L., Santamaría, J., Mackintosh, N. J., & Chamizo, V. D. (2009). Single landmark learning: sex differences in a navigation task. *Learning and Motivation*, 40, 46-61.

Gallistel, C. R. (1990). *The organization of learning*. Cambridge, MA: MIT Press.

Horne, M. R., & Pearce, J. M. (2009). A landmark blocks searching for a hidden platform in an environment with a distinctive shape after extended pretraining. *Learning & Behavior*, 37, 167–178.

Kimura, D. (1999). *Sex and Cognition*. The MIT Press, Cambridge, MA.

Miller, N. Y., & Shettleworth, S. J. (2007). Learning about environmental geometry: An associative model. *Journal of Experimental Psychology: Animal Behavior Processes*, 33, 191–212.

Hayward, A., Good, M. A., & Pearce, J. M. (2004). Failure of a landmark to restrict spatial learning based on the shape of the environment. *The Quarterly Journal of Experimental Psychology*, 57B, 289-314.

McGregor, A., Hayward, A. J., Pearce, J. M., & Good, M. A. (2004). Hippocampal lesions disrupt navigation based on the shape of the environment. *Behavioral Neuroscience*, 118, 1011–1021.

Morris, R. G. M. (1981). Spatial localization does not require the presence of local cues. *Learning & Motivation*, 12, 239-261.

Pearce, J. M. (2009). An associative analysis of spatial learning. *Quarterly Journal of Experimental Psychology*, 62, 1665–1684.

Rodríguez, C. A., Chamizo, V. D., & Mackintosh, N. J. (2011). Overshadowing and blocking between landmark learning and shape learning: the importance of sex differences. *Learning & Behavior*, 39, 324-335.

Rodríguez, C. A., Torres, A. A., Mackintosh, N. J., & Chamizo, V. D. (2010). Sex differences in the strategies used by rats to solve a navigation task. *Journal of Experimental Psychology: Animal Behavior Processes*, 36, 395-401.

Tommasi, L., Chiandetti, C., Pecchia, T., Sovrano, V. A., & Vallortigara, G. (2012). From natural geometry to spatial cognition. *Neuroscience and Biobehavioral Reviews*, 36, 799-824.

Trobalon, J. B., Miguelez, D., McLaren, I.P.L., & Mackintosh, N.J. (2003). Intradimensional and extradimensional shifts in spatial learning. *Journal of Experimental Psychology: Animal Behavior Processes*, 29, 143-152.

Williams, C. L., Barnett, A. M., & Meck, W. H. (1990). Organizational effects of early gonadal secretions on sexual differentiation in spatial memory. *Behavioral Neuroscience*, 104, 84–97.