BEHAVIOURAL BRAIN RESEARCH

A characterization of performance by men and women in a virtual Morris water task:
A large and reliable sex difference

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Abstract

In many mammalian species, it is known that males and females differ in place learning ability. The performance by men and women is commonly reported to also differ, despite a large amount of variability and ambiguity in measuring spatial abilities. In the non-human literature, the gold standard for measuring place learning ability in mammals is the Morris water task. This task requires subjects to use the spatial arrangement of cues outside of a circular pool to swim to a hidden goal platform located in a fixed location. We used a computerized version of the Morris water task to assess whether this task will generalize into the human domain and to examine whether sex differences exist in this domain of topographical learning and memory. Across three separate experiments, varying in attempts to maximize spatial performance, we consistently found males navigate to the hidden platform better than females across a variety of measures. The effect sizes of these differences are some of the largest ever reported and are robust and replicable across experiments. These results are the first to demonstrate the effectiveness and utility of the virtual Morris water task for humans and show a robust sex difference in virtual place learning. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Sex difference; Virtual reality; Morris water task; Spatial memory; Hippocampus; Place learning; Spatial ability

Since the 1970s, the idea that men are superior to women at spatial abilities has entered into most textbooks in psychology and behavioral neuroscience [19]. However, when one reviews the relevant literature, it quickly becomes apparent that the sex differences in performance in spatial tasks are small, reliable only during a portion of development, or are not consistently found across studies [6]. There are a number of reasons for this. First, there is ambiguity in what exactly constitutes spatial ability. For example, the ability to match rotated 3-dimensional images mentally, for many, is the gold standard of spatial abilities [17]. However, it is not clear to others how this is an appropriate test of spatial ability [1], analogous to the sex difference in spatial navigation reported in other mammalian species [12]. In addition, even in mental rotation tasks there are inconsistencies about whether males and females perform differently [1]. Moreover, tests of abilities to perceive spatial illusions [13], map-learning [14], route learning [3], pointing to places [5], and judging water levels [18] are all clumped together as spatial tasks. Nonetheless, this conglomerate generalizes into widely accepted sex differences in wayfinding or orienting.

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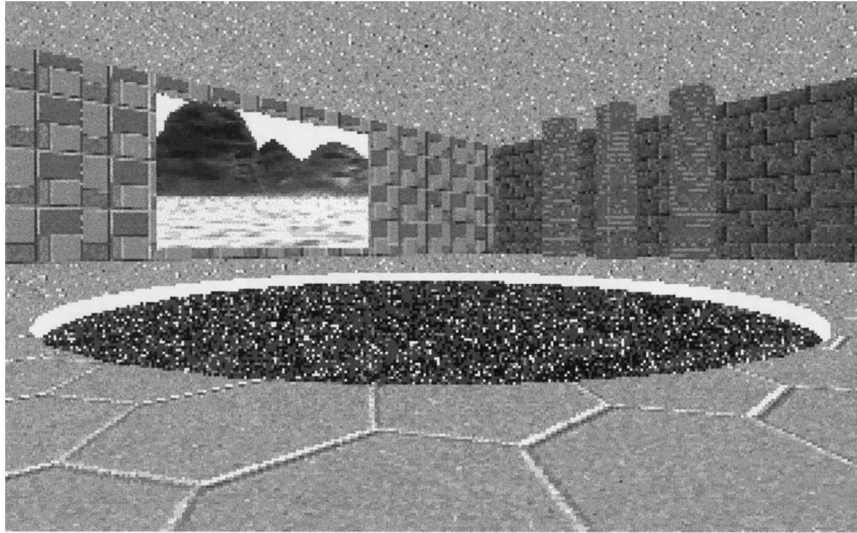
Fig. 1. A black and white picture of the computerized Morris water task with the virtual pool in the room. The actual graphics used during the experiments were in color.

In 1981, Morris described an elegant and powerful procedure for measuring spatial navigation in rats [9]. He used a circular swimming pool containing a hidden goal platform in a fixed location. The rats cannot see, smell, hear, or in any other way use a local landmark associated with the hidden goal, but can use the topographical relationships among visible, distal cues in the room surrounding the pool to learn to swim to the goal. The analysis of behavior in this task has proven to be remarkably fruitful, allowing pursuit of spatial learning processes to neural circuit [16], cellular [10], and molecular levels [10]. Morris and others have shown that the ability to learn to navigate accurately in this task depends critically upon the integrity and plasticity of circuitry in the hippocampal formation (but see [20]). Moreover, there is evidence that species which utilize spatial memory to retrieve food or eggs have larger hippocampi and routinely display sex differences in favor of the gender that performs these tasks [15]. Because of a huge database and understanding of the Morris water task, it is now considered the gold standard test to assess spatial memory in non-primates [11].

In this paper, an attempt is made to address two questions: (1) can a version of the Morris water task be successfully used to test humans, and (2) will this kind of spatial learning task reveal any differences between men and women? Using computerized 3D graphics, 20 male and 20 female undergraduates were placed in a circular pool in a room with various distal cues, but no local cues (Fig. 1). Participants were to escape from the water as quickly as possible by using a joystick to navigate to a platform hidden under the surface of the water. Participants started from four different locations, five times each for a total of 20 trials. We found a large sex difference in performance of this task, using

the now-standard measures of learning from rodent work. Specifically, males swim for significantly shorter times to find the platform (Fig. 2a). After training, in a probe trial in which the platform is removed from the pool, males spend significantly more of their swim distance in the quadrant of the pool where the platform had previously been positioned (Fig. 2b) and are more accurate in their initial trajectory toward the platform (Fig. 2c). Furthermore, males swim over the area of the pool where the platform used to be located significantly more times than females (Fig. 2d). The swim paths for the male and female with median performance on the probe trial can be seen in Fig. 3. The effect sizes of these differences range from 0.54 to 1.02 (Table 1, column 1), which are some of the largest effect sizes ever reported. In swimming to a visible platform in a different area of the pool, there were no differences between males and females in time to find the platform ($F(1, 31) = 0.56$, $P = 0.46$). This lack of difference in swimming to the visible platform and no differences in swim speed ($t(38) = 0.40$, $P = 0.69$) between the two groups on their probe trial suggests that the differences between the two groups in finding the hidden platform are not due to motivational, sensory, or motor differences interacting with the computer program.

During debriefing, those who used an inefficient strategy, involving indirect or circuitous paths, reported that they believed the platform was moving from trial to trial. In an attempt to use a non-verbal method to make it more apparent that the platform was not moving, a modified version of the virtual Morris water task was used. Specifically, 20 male and 18 female undergraduates who did not participate in the first experiment were placed in the same virtual task environment. Participants again were asked to escape from
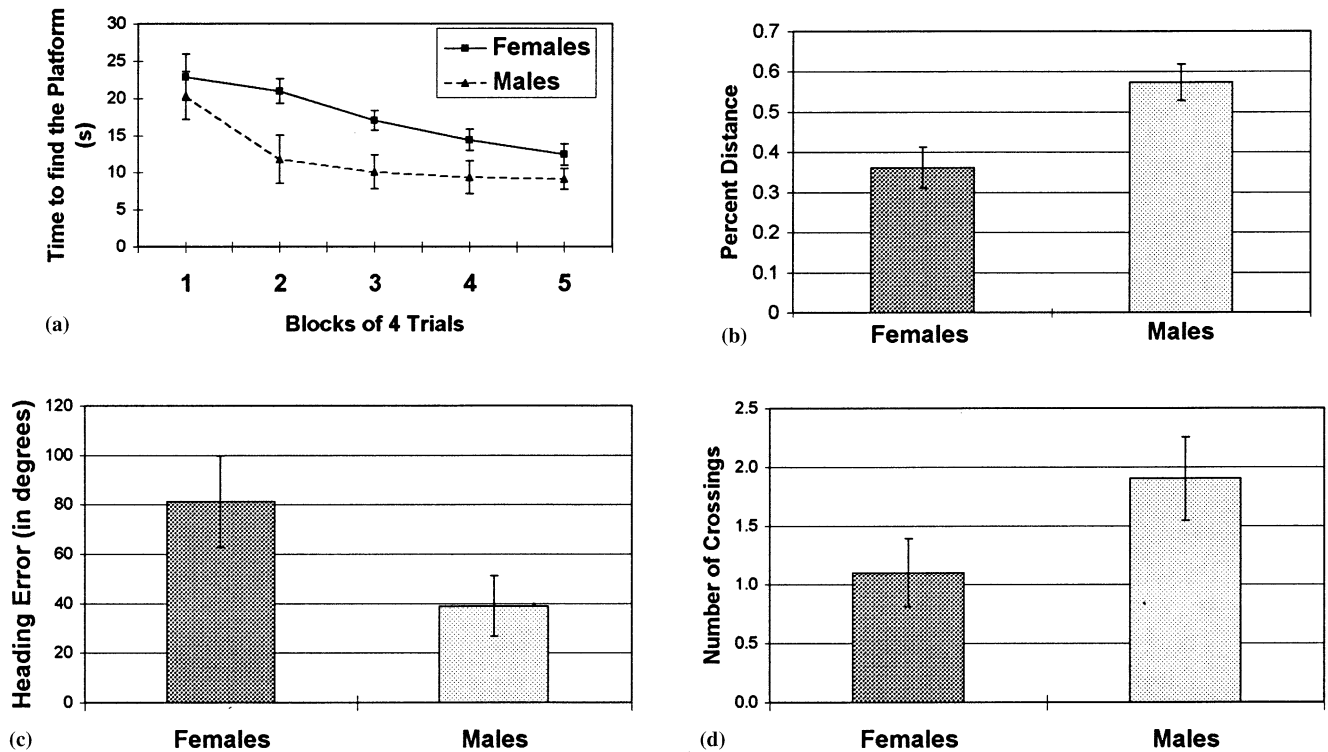
Fig. 2. (a). Mean time (+ S.E.M.) to swim to the platform for males and females in Experiment 1. Males swam to the platform significantly faster than females, $F(1, 38) = 7.33$, $P = 0.01$. (b) Mean percent of swim distance (+ S.E.M.) spent in the quadrant of the pool that previously contained the hidden platform. Males spent significantly more distance in this quadrant of the pool than females, $t(38) = 3.13$, $P = 0.003$. (c) Mean initial heading error (+ S.E.M.) toward the platform for males and females. Males were significantly more accurate in swimming toward the platform, $t(38) = -3.44$, $P = 0.001$. (d) Number of platform crossings on the probe trial for males and females. Males cross the platform location significantly more times than females, $t(38) = 1.75$, $P = 0.045$, one-tailed.

the water as quickly as possible by using a joystick to navigate. For the first trial, the top of the platform was raised out of the water so that it was visible. On the next trial, the platform was in the same place but sunk beneath the surface of the water so that it was hidden. This alternation of visible with hidden trials was repeated 32 times with participants starting from four different locations. After this training, a probe trial was conducted in which the platform was removed from the pool. Using this procedure, again, males display better spatial navigation. Males find the platform significantly faster (Fig. 4a). Moreover, in the probe trial, males spend significantly more swim distance in the quadrant of the pool where the platform had been positioned ($t(36) = 2.46$, $P = 0.019$) and have significantly more platform crossings then females ($t(36) = 3.08$, $P = 0.004$). The effect sizes of these differences range from 0.75 to 0.90 (Table 1, column 2). Males and females did not differ in time to swim to the visible platform ($F(1, 36) = 2.93$, $P = 0.096$). There were no differences in heading errors toward the platform ($t(36) = 0.44$, $P = 0.66$) or swim speed ($t(36) = 0.77$, $P = 0.44$) on the probe trial.

Given that this non-verbal attempt at changing the participants' strategies did not reduce the sex difference,

a more direct linguistic approach to change these strategies was adopted. Specifically, we changed the instructions to indicate that there was a platform in the pool that was submerged just under the surface of the water. These instructions also indicated that the platform was always in the same location, and instructed the participants to use the scenery and landmarks in the room to remember the location of the platform. We felt that this provided the most amount of information about solving the task except for actually indicating the exact location of the platform. There were 21 males and 27 female undergraduates who did not participate in the other experiments who were placed in the same virtual environment. Again, men were significantly faster at finding the platform (Fig. 4b). During the probe trial, males spend significantly more swim distance in the quadrant of the pool where the platform was previously located ($t(46) = 2.88$, $P = 0.006$) and had smaller heading errors toward the platform ($t(46) = 2.33$, $P = 0.025$). Furthermore, males had significantly more platform crossings then females ($t(46) = 4.17$, $P < 0.001$). The effect sizes of these differences range from 0.65 to 1.04 (Table 1, column 3). Again, there was no difference in swim speed ($t(46) = 0.34$, $P = 0$ 0.73).
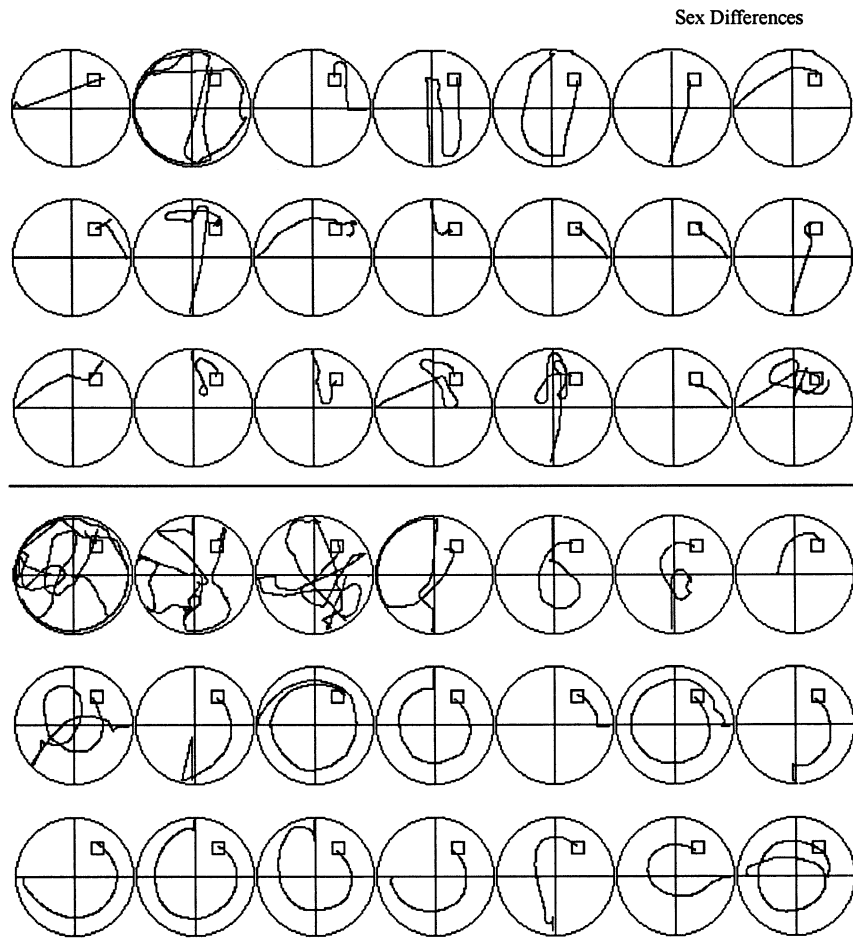
Sex Differences

Fig. 3. Swim paths for the male and female with median performance on the probe trial in experiment 1. Trial 1 starts in the upper lefthand corner and proceeds left to right. The last trial is the probe trial in which the platform is removed from the pool. The male paths are the upper paths and the female paths are the lower paths.

This navigation involved virtual reality and not actual route finding, but we do not believe that this accounts for the observed sex difference. Using this virtual reality modality in swimming to a visible platform that does not require a spatial strategy, males and females perform equally on all measures. This suggests that the observed sex differences in spatial navigation

Table 1
Experimental details

Dependent variable	Exp. 1	Exp. 2	Exp.3
Probe percent	1.02**	0.75**	0.78**
Platform crossings	0.54	0.90**	1.04**
Heading error	0.93**	0.14	0.65**

Effect sizes (($Mean_{Male} - Mean_{Female}$)/S.D. common) for percent of distance spent in the quadrant of the pool that previously contained the hidden platform (probe percent), number of platform crossings during the probe trial (platform crossings), and initial heading error toward the platform (heading error).
Note that across all three experiments across a variety of measures, these effect sizes are large and replicable.
**$P < 0.05$.

are not due to motivational, motor, or sensory differences interacting with the computer program. As revealed by a post-experimental questionnaire, males have more experience with computer games that involve this type of computer graphics. However, this does not account for the difference in spatial performance observed here. Specifically, a hierarchical regression revealed that sex predicted spatial performance over and above that predicted by computer game experience ($R^2 = 0.15$, $F_{inc}(1,118) = 10.24$, $P < 0.001$). Nonetheless, this paradigmatic difference should be kept in mind when comparing these results to those of other experiments. For example, sources of information derived from the head and the rest of the body during real locomotion are absent in our virtual task, yet these seem to be important for rodents to navigate efficiently [8]. That point notwithstanding, both males and females are equally deprived of such sources of information, so this alone can not account for the observed differences.

Returning to our original hypotheses, we find that a computerized Morris water task can effectively be em-
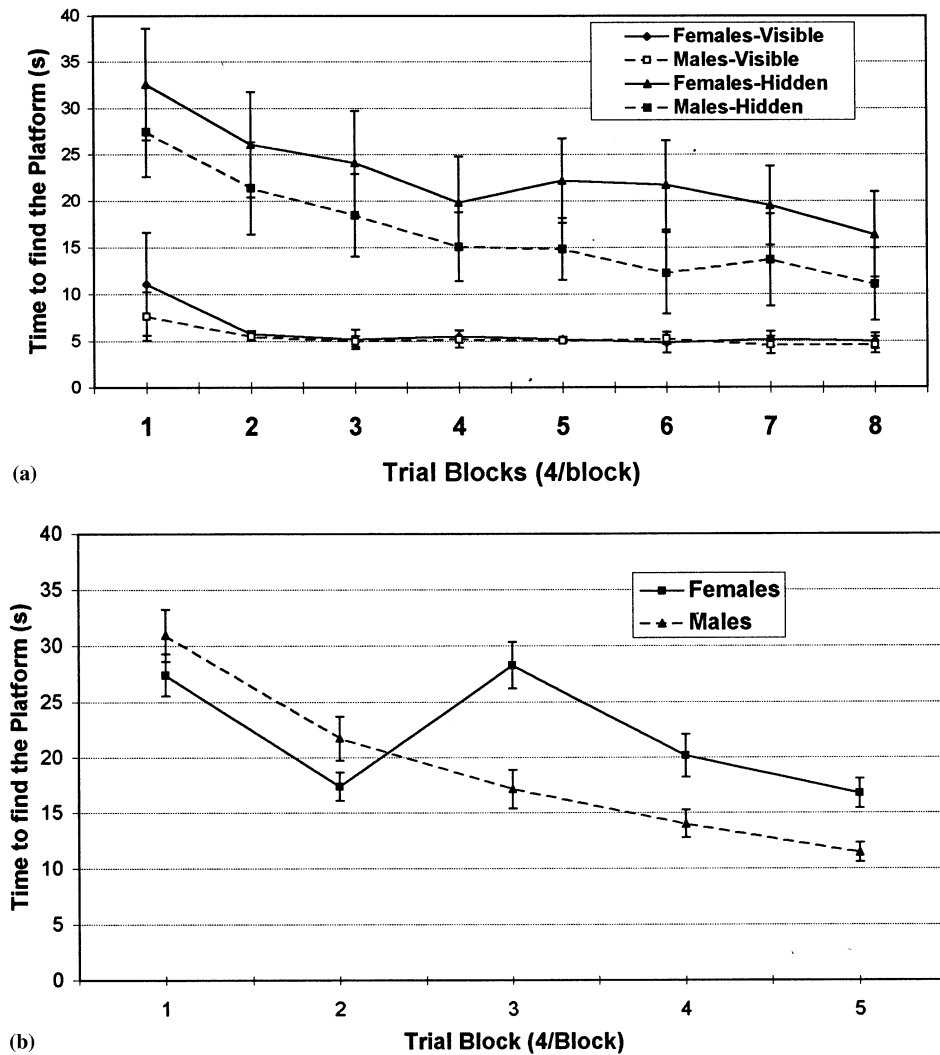
Fig. 4. (a). Mean time (+ S.E.M.) to find the platform for males and females in the alternating visible and hidden platform trials. Males swim to the platform significantly faster than females during the hidden platform trials, $F(1,36) = 4.67$, $P = 0.037$, but do not differ in escape latencies during swimming to the visible platform, $F(1,36) = 3.27$, $P = 0.079$. (b) Mean time (+ S.E.M.) to find the hidden platform for males and females in exp 3. Males swim to the platform significantly faster than females, $F1,46) = 10.89$, $P = 0.002$.

ployed with humans, and it reveals very large sex differences in performance. These sex differences may be due to a variety of factors. As has been pointed out previously [7], due to social pressures, males often have more experience in navigation and spatial performance. Moreover, it may be that different hormone levels contribute to differential brain organization and hence result in varying spatial strategy preferences for males and females [4]. Additionally, evolutionary pressures may have influenced preferential strategies that male and females use in spatial navigation [2]. Any of these factors or a combination of them may contribute to this robust and replicable male advantage for spatial navigation in a virtual Morris water task. The development and modification of the virtual place learning task we describe here should substantially facilitate the experimental analysis of spatial learning and the evaluation of relevant neurodevelopmental factors.

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