

Delayed Development of Place Navigation Compared to Directional Responding in Young Rats

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Recent work from our laboratory demonstrates that both young and adult rats show a preference for directional responding over place navigation in the Morris water task. Based on these findings, previous studies on the postnatal development of spatial learning have most likely assessed the ontogeny of directional responding instead of true place navigation. Here, we examined the development of directional responding and place navigation among young male and female rats using two variants of the Morris water task that specifically require directional and place responses. In the place variant, the hidden platform remained in the same absolute spatial location regardless of pool position. In the direction variant, the platform remained in the same direction in the room regardless of pool position. We found that ability to solve the direction task emerged around 20 to 21 days of age, whereas ability to solve the place task did not emerge until 26 to 27 days of age. These findings indicate that directional responding and place navigation exhibit different developmental trajectories and suggest that the 2 forms of navigation have different neurobiological bases.

Keywords: water maze, spatial memory, hippocampus, sex difference, preweanling

Spatial navigational abilities in the rat develop across the first few postnatal months (Akers & Hamilton, 2007; Brown & Kraemer, 1997; Brown & Whishaw, 2000; Carman, Booze, & Mactutus, 2002; Carman & Mactutus, 2001; Kraemer & Randall, 1995; Loewen, Wallace, & Whishaw, 2005; Rauch & Raskin, 1984; Rossier & Schenk, 2003; Rudy & Paylor, 1988; Rudy, Stadler-Morris, & Albert, 1987; Schenk, 1985; Tonkiss, Shultz, & Galler, 1993). In the Morris water task (Morris, 1981, 1984), ability to solve the hidden platform version of the task emerges around the end of the third postnatal week (Akers & Hamilton, 2007; Brown & Kraemer, 1997; Brown & Whishaw, 2000; Carman & Mactutus, 2001; Kraemer & Randall, 1995; Rudy & Paylor, 1988; Rudy et al., 1987; Schenk, 1985; Tonkiss et al., 1993) and improves during the weeks thereafter (Schenk, 1985; Tonkiss et al., 1993).

In studies on the development of spatial learning in the Morris water task, it is typically assumed that young rats find the hidden platform by navigating to its specific spatial location relative to a constellation of distal cues. Recent findings, however, question this assumption. Specifically, it was discovered that adult rats do not search for the platform at its absolute

spatial location when the pool is repositioned in the testing room during a posttraining probe trial (Hamilton et al., 2008; Hamilton, Akers, Weisend, & Sutherland, 2007). Instead, they continue to swim in the same direction that the platform was located during training, resulting in a search for the platform at a spatial location that was never trained. This tendency to solve the Morris water task by swimming in a particular direction rather than by swimming to a specific place was also found in young rats at 24 days of age (Akers, Candelaria, & Hamilton, 2007). Together, these studies indicate that directional responding is the default strategy by which rats solve the Morris water task regardless of age, which would suggest that previous studies on the development of spatial learning in this task (Akers & Hamilton, 2007; Brown & Kraemer, 1997; Brown & Whishaw, 2000; Carman & Mactutus, 2001; Kraemer & Randall, 1995; Rudy & Paylor, 1988; Rudy et al., 1987; Schenk, 1985; Tonkiss et al., 1993) most likely characterize the ontogeny of directional responding rather than true place navigation.

To disambiguate directional responding and place navigation in the Morris water task, we developed two variants of the task that specifically require either direction or place responses (Hamilton et al., 2008). In both variants of the task, the pool is repositioned in the distal cue environment for every trial. In the place variant, the hidden platform remains in the same absolute spatial location regardless of the pool position, thus requiring rats to consistently navigate to a precise place within the distal cue environment. In the direction variant, the hidden platform remains in the same direction (e.g., in the north pool quadrant) regardless of the pool position, thus requiring rats to consistently navigate in a particular direction within the distal cue environment. Here, to determine whether directional responding and place navigation exhibit different developmental trajectories, we examined young male and

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female rats' ability to solve the direction and place variants of the Morris water task between 18 and 27 days of age.

Method

Subjects

Subjects were 160 Long-Evans hooded rat pups born from dams bred at the Psychology Department Animal Facility at the University of New Mexico (originally from Harlan stock). The day of birth was designated as P0. Litter size ranged from 7 to 15 pups. Rat pups were housed with their dam in plastic cages ($51 \times 25 \times 22$ cm) with a 12-hr light–dark cycle (lights on at 8 a.m.). Food and water were provided ad libitum. Rat received two consecutive days of training at one of five different ages—P18–19, P20–21, P22–23, P24–25, or P26–27. Within each age group, 8 males and 8 females were trained in the place task, and 8 males and 8 females were trained in the direction task. Within each age group, a maximum of one pup per litter was assigned to each combination of task and sex. On the day prior to training, rats were ear-notched for identification. Rats were weaned after their participation in the experiment.

Apparatus

A circular white pool (1.5 m diameter, 48 cm high) was set on a wooden frame (48 cm high) that was attached to wheels, allowing the pool to be moved when full of water. The pool was filled to a depth of 27 cm with $\sim 25^\circ\text{C}$ water, which was made opaque by the addition of a small amount of nontoxic powdered white paint. The platform (15×15 cm), located ~ 1 cm below the water surface, was made of white plastic and covered in a wire grid to assist rats in climbing onto it. Several distal visual cues were located around the room. Behavior was videotaped by an overhead camera attached to a digital camcorder. Videos were transferred to a Linux workstation for tracking and analysis.

Procedure

Rats received six sessions of training per day for two consecutive days; each session was comprised of four trials. On every trial, the pool was moved to one of four different positions located around a central point (Figure 1A). For the place task, the platform remained in the same absolute location in the room across trials regardless of pool position (Figure 1B); thus, the platform occupied different relative locations in the pool from trial to trial. For the direction task, the platform remained in the same relative location in the pool across trials regardless of pool position (Figure 1C); thus, the platform occupied different locations in the room from trial to trial. For example, Figure 1C shows the platform locations for a rat in the direction task trained with the platform in the N pool quadrant. Within the direction task, equal numbers of rats were trained with the platform located in the center of the N, S, E, and W pool quadrants. For more detail regarding pool positions during training, see description of Experiment 5 in Hamilton et al. (2008).

During each training session, each of the four pool positions was used once. Across training sessions, the order of pool positions followed a pseudorandom sequence. From the location of the holding cages in the testing room (along the N wall of the room),

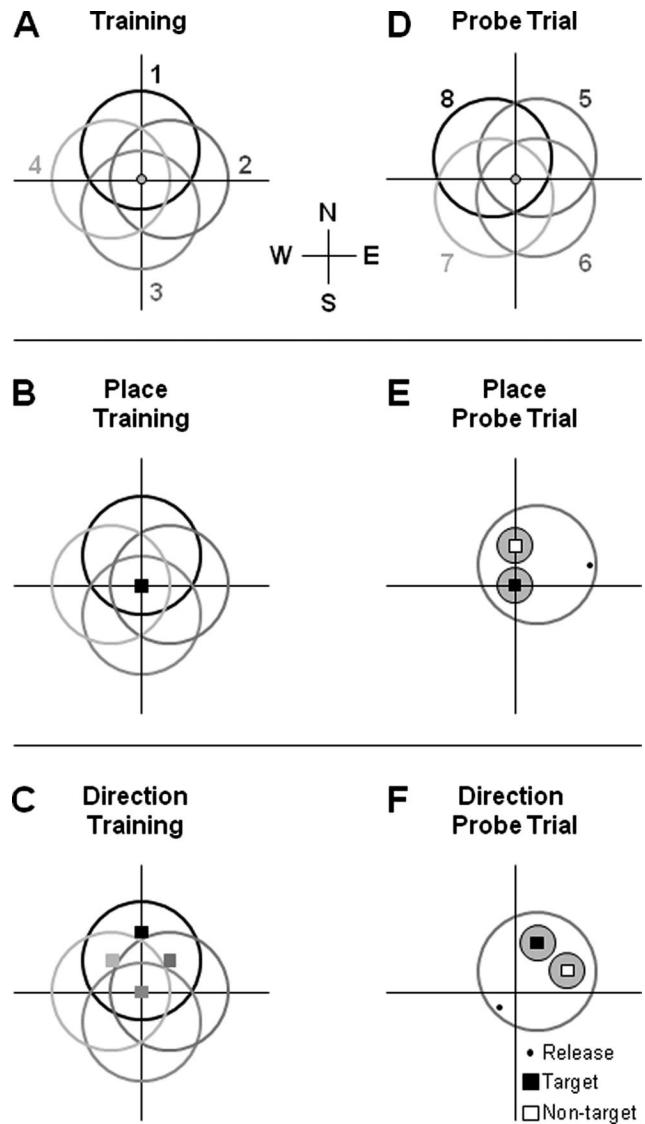


Figure 1. (A) Pool positions used during training for place and direction tasks. (B) In the place task, the platform occupied the same absolute location in the room throughout training regardless of pool position. (C) In the place task, the platform occupied the same relative location in the pool throughout training regardless of pool position (e.g., the N quadrant). (D) Pool positions used during the probe trials for place and direction tasks. (E) An example of probe trial pool position, target and nontarget locations, and release point for a rat in the place task. The small gray squares surrounding each of the critical locations served as regions of analysis for some probe trial dependent measures. (F) An example of probe trial pool position, target and nontarget locations, and release point for a rat in the direction task that was trained with the platform in the N pool quadrant.

rats were carried by the experimenter and released into the pool with their heads facing the pool wall. Rats were released from one of four points equally spaced around the perimeter of the pool (N, S, E, or W) with the constraint that, for a given trial, the release point closest to the platform was not used. Thus, there were three possible release points for each pool position (e.g., if the platform was in the N pool quadrant, the three possible release points were

S, E, and W). Each release point at each pool position was used an equal number of times throughout training following a pseudorandom sequence. To prevent fatigue and hypothermia in the rat pups, trials lasted a maximum of 45 s. If a rat did not find the platform within this time limit, it was retrieved by the experimenter and placed on the platform. Rats remained on the platform for approximately 5 s before being removed by the experimenter; this duration was selected to further limit exposure to the cool water and to reinforce navigation to the platform by quickly removing the rat from the water. The dependent measure during training was latency to reach the platform. If a rat did not reach the platform before the end of a trial, a latency of 45 s was recorded. The intertrial interval was 5 to 10 min; sessions were run in succession with no additional intersession interval.

Because performance in the water task is impaired by hypothermia (Iivonen, Nurminen, Harri, Tanila, & Puolivali, 2003; Moser & Anderson, 1994; Rauch, Welch, & Gallego, 1989), to which young rats may be particularly vulnerable, care was taken to maintain rats' body temperatures throughout training. Immediately after each trial, rats were towel-dried before being returned to their individual holding cages, which contained an ample amount of bedding and were located in close proximity to a heater. After each session, rats' core body temperatures were measured using a rectal thermometer (Physitemp Instruments, Clifton, NJ). Rats did not begin the next session of trials until their core body temperature was within 1 °C of baseline body temperature (37 °C).

After the last session on each day of training, a 30 s probe trial was conducted with the platform removed from the pool. Probe trials occurred with the pool at one of four different positions that were not used during training (Figure 1D). Within each condition (age, task, and sex), the four pool positions were used an equal number of times for each day of testing. For each rat, a different probe pool position was used on each day. The goal of the probe trial was to evaluate how well rats in each task learned to navigate to a particular target location (i.e., the absolute place in the room or the relative direction within the pool). Therefore, dependent measures were taken for the target location and a nontarget comparison location rotated 90° clockwise or counterclockwise around the center of the pool from the target location. The release point for the probe trial was always equidistant from the critical locations and located at the opposite side of the pool. For example, Figure 1E shows the critical locations and release point for a rat in the place task. In this example, the rat was tested with the pool in Position 5 (see Figure 1D); the target location was the absolute place the platform was located during training, the nontarget location was 90° clockwise of the target location, and the release point was located at the E side of the pool. Figure 1F shows the critical locations and release point for a rat in the direction task that was trained with the platform in the N pool quadrant. In this example, the rat was tested with the pool in Position 5; the target location was in the center of the N quadrant, the nontarget location was 90° clockwise of the target location, and the release point was located at the SW side of the pool. Whether the nontarget location was located clockwise or counterclockwise of the target location was counterbalanced within tasks and pool positions. For more detail regarding pool positions and critical locations during probe trials, see description of Experiment 5 in Hamilton et al. (2008).

Dependent measures during the probe trial were latency to enter a circular region (66 cm in diameter) centered on each of

the critical locations, time spent in each of the circular regions, average proximity of the swim path to each of the critical locations (adapted from Gallagher, Burwell, & Burchinal, 1993), and number of times each critical location was crossed. The first dependent measure provides an index of the directness of the rat's initial trajectory to the critical regions. The latter three dependent measures provide different indexes—with varying levels of sensitivity—of the rat's persistence in searching for the platform at the critical regions/locations.

Results

Training

Performance during training was initially analyzed using omnibus analysis of variance (ANOVA) with age, task, and sex as between-subjects factors and day as a within-subject factor. Although Figure 2 displays training data for each session, this factor was not included in the analyses to simplify presentation of the results. We found a significant Age \times Task \times Sex \times Day interaction, $F(4, 140) = 2.74, p = .031$, a significant Age \times Task \times Day interaction, $F(4, 140) = 4.60, p = .002$, and a significant effect of day, $F(1, 140) = 701.98, p < .001$, on latency to reach the platform. To further analyze these interactions, separate ANOVAs with task and sex as between-subjects factors and day as a within-subject factor were performed at each level of age.

At P18–19 (Figure 2A), there was a significant Task \times Sex \times Day interaction, $F(1, 28) = 4.57, p = .041$, and a significant effect

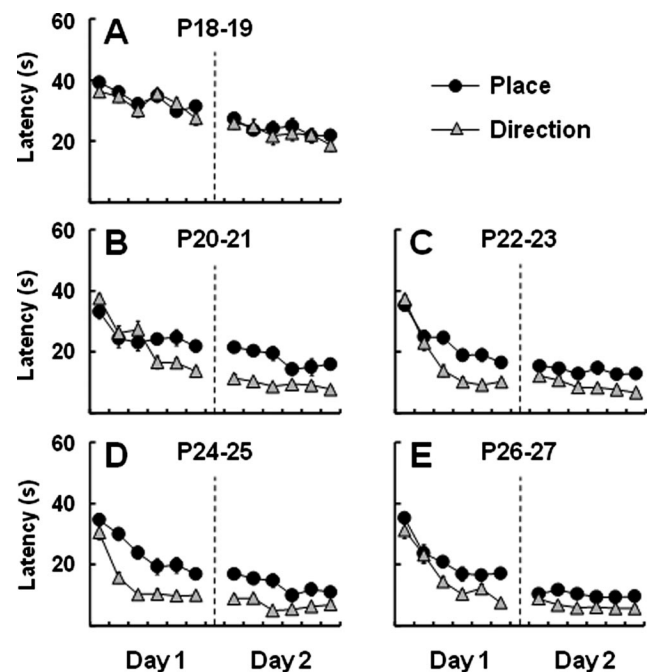


Figure 2. (A) At P18–19, there was no difference between rats in the place and direction tasks in latency to reach the platform during training. (B) At P20–21, rats in the direction task reached the platform faster than rats in the place task on the second day of training. This difference between tasks persisted across both days of training for (C) P22–23 rats, (D) P24–25 rats, and (E) P26–27 rats.

of day, $F(1, 28) = 96.01, p < .001$. To further analyze the interaction, separate ANOVAs were performed within each task. Within the place task, there was a significant Sex \times Day interaction, $F(1, 14) = 6.36, p = .024$. Female rats reached the platform faster than male rats on the first day of training (females: $M = 32.33$ s, $SEM = 0.78$; males: $M = 35.47$ s, $SEM = 0.92$), $p = .021$, but there was no difference between males and females on the second day of training (females: $M = 25.41$ s, $SEM = 1.82$; males: $M = 22.48$ s, $SEM = 2.08$), $p = .306$. There was also a significant effect of day, $F(1, 14) = 68.30, p < .001$, indicating that rats reached the platform faster on the second day as compared to the first day of training. Within the direction task, there was only a significant effect of day, $F(1, 14) = 37.26, p < .001$.

At P20–21 (Figure 2B), there was a significant Task \times Day interaction, $F(1, 28) = 10.08, p = .004$, and a significant effect of day, $F(1, 28) = 117.96, p < .001$. On the first day of training, there was no difference between tasks in latency to reach the platform, $p = .189$. On the second day of training, however, rats in the direction task reached the platform faster than rats in the place task, $p < .001$.

At P22–23 (Figure 2C), there was a significant effect of task, $F(1, 28) = 20.93, p < .001$, and a significant effect of day, $F(1, 28) = 134.06, p < .001$. Rats in the direction task reached the platform faster than rats in the place task on both the first day of training, $p < .001$, and the second day of training, $p = .002$.

At P24–25 (Figure 2D), there was a significant effect of task, $F(1, 28) = 39.58, p < .001$, and a significant effect of day, $F(1, 28) = 144.76, p < .001$. Rats in the direction task reached the platform faster than rats in the place task on both the first day of training, $p < .001$, and the second day of training, $p < .001$. The presence of a significant Task \times Day interaction, $F(1, 28) = 4.36, p = .046$, however, indicates that the difference between tasks was larger on the first day than on the second day of training. There was also a significant Sex \times Day interaction, $F(1, 28) = 5.89, p = .022$. Females exhibited a greater reduction in latency to reach the platform across training days (Day 1–Day 2: $M = 11.01$ s, $SEM = 1.25$) compared to males (Day 1–Day 2: $M = 7.32$ s, $SEM = 1.00$), $p = .028$.

At P26–27 (Figure 2E), there was a significant effect of task, $F(1, 28) = 40.75, p < .001$, and a significant effect of day, $F(1, 28) = 363.18, p < .001$. Rats in the direction task reached the platform faster than rats in the place task on both the first day of training, $p < .001$, and the second day of training, $p < .001$.

Probe Trials

Performance during the probe trials were initially analyzed using omnibus ANOVAs with age, task, and sex as between-subjects factors and location (target vs. nontarget) and day as within-subject factors. We found significant Age \times Task \times Location interactions for time spent in the critical regions, $F(4, 140) = 4.23, p = .003$, and average proximity to the critical locations, $F(4, 140) = 2.86, p = .025$. We also found significant Age \times Location interactions for time, $F(4, 140) = 5.85, p < .001$, and number of critical location crosses, $F(4, 140) = 6.37, p < .001$; significant Task \times Location interactions for latency to enter the critical regions, $F(1, 140) = 12.56, p = .001$, time, $F(1, 140) = 60.94, p < .001$, proximity, $F(1, 140) = 30.41, p < .001$, and crosses, $F(1, 140) = 35.58, p < .001$; and a significant Day \times

Location interaction for crosses, $F(1, 140) = 4.98, p = .027$. There were also significant effects of age for all four dependent measures; latency, $F(4, 140) = 12.52, p < .001$; time, $F(4, 140) = 18.57, p < .001$; proximity, $F(4, 140) = 24.03, p < .001$; crosses, $F(4, 140) = 12.70, p < .001$; significant effects of task for time, $F(1, 140) = 26.42, p < .001$, proximity, $F(1, 140) = 5.61, p = .019$, and crosses, $F(1, 140) = 19.52, p < .001$; significant effects of day for time, $F(1, 140) = 14.65, p < .001$, proximity, $F(1, 140) = 20.04, p < .001$, and crosses, $F(1, 140) = 10.19, p = .002$; and significant effects of Location for all dependent measures; latency, $F(1, 140) = 32.22, p < .001$; time, $F(1, 140) = 88.45, p < .001$; proximity, $F(1, 140) = 61.87, p < .001$; crosses, $F(1, 140) = 59.01, p < .001$. To further analyze these interactions, separate ANOVAs with task as a between-subjects factor and location and day as within-subject factors were performed at each level of Age. Because no effects involving sex were significant in the omnibus ANOVAs, $ps > .080$, this factor was dropped from subsequent analyses.

At P18–19 (Figures 3A–3D), there were significant effects of day for time, $F(1, 30) = 4.18, p = .049$, and proximity, $F(1, 30) = 5.05, p = .032$, indicating that rats spent more time in the critical regions and swam closer to the critical locations on the second day as compared to the first day of testing. No effects involving location were significant, $ps > .107$, indicating that neither rats in the direction task nor rats in the place task discriminated between target and nontarget regions/locations.

At P20–21 (Figures 4A–4D), there were significant Task \times Location interactions for time, $F(1, 30) = 11.94, p = .002$, proximity, $F(1, 30) = 6.66, p = .015$, and crosses, $F(1, 30) = 11.09, p = .002$. Across both days of testing, rats in the direction task spent more time in the target region than the nontarget region, $p < .001$, swam closer to the target location than the nontarget location, $p < .001$, and crossed the target location more often than the nontarget location, $p = .003$. Rats in the place task, however, did not discriminate between the target and nontarget region/location, $ps > .181$. There were significant effects of task for latency, $F(1, 30) = 4.42, p = .044$, time, $F(1, 30) = 7.51, p = .010$, and proximity, $F(1, 30) = 9.08, p = .005$, indicating that rats in the direction task reached the critical regions faster, spent more time in the critical regions, and swam closer to the critical locations than rats in the place task. There were significant effects of location for all four dependent measures; latency, $F(1, 30) = 8.63, p = .006$; time, $F(1, 30) = 19.01, p < .001$; proximity, $F(1, 30) = 21.59, p < .001$, crosses, $F(1, 30) = 4.29, p = .047$; indicating that rats reached the target region faster, spent more time in the target region, swam closer to the target location, and crossed the target location more often than the nontarget region/location. Finally, there were significant effects of day for all four dependent measures; latency, $F(1, 30) = 4.52, p = .042$; time, $F(1, 30) = 13.63, p < .001$; proximity, $F(1, 30) = 12.31, p = .001$; crosses, $F(1, 30) = 6.00, p = .020$; indicating that rats reached the critical regions faster, spent more time in the critical regions, swam closer to the critical locations, and crossed the critical locations more often on the second day of testing as compared to the first day of testing.

At P22–23 (Figures 5A–5D), there were significant Task \times Location interactions for all four dependent measures; latency, $F(1, 30) = 4.75, p = .037$; time, $F(1, 30) = 18.47, p < .001$; proximity, $F(1, 30) = 11.54, p = .002$, crosses, $F(1, 30) = 10.63,$

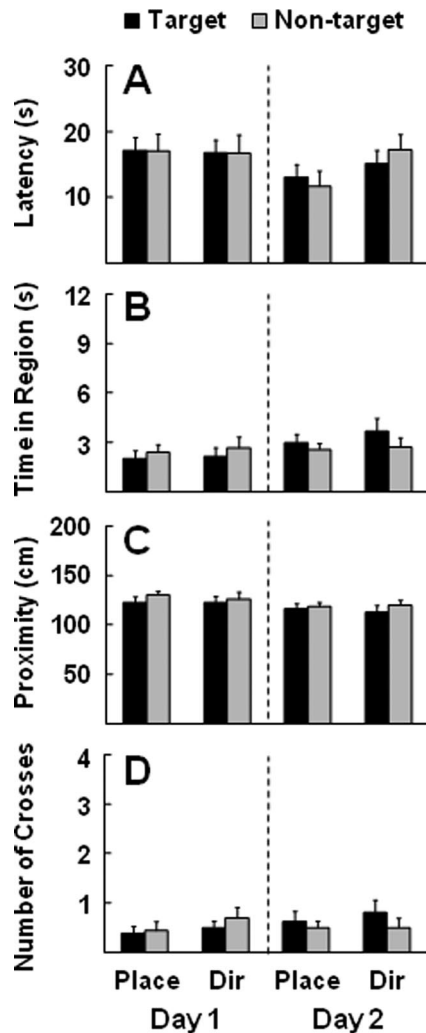


Figure 3. At P18–19, neither rats in the place task nor rats in the direction (DIR) task discriminated between the target and nontarget regions/locations during the probe trials. (A) Latency to reach the critical regions. (B) Time spent in the critical regions. (C) Average proximity of swim path from the critical locations. (D) Number of times the critical locations were crossed.

$p = .003$. Across both days of testing, rats in the direction task reached the target region faster than the nontarget region, $p = .019$, spent more time in the target region than the nontarget region, $p < .001$, swam closer to the target location than the nontarget location, $p = .003$, and crossed the target location more often than the nontarget location, $p = .001$. Rats in the place task showed no discrimination between the target and nontarget region/location, $ps > .556$. There were also significant effects of location for time, $F(1, 30) = 17.27$, $p < .001$, proximity, $F(1, 30) = 7.63$, $p = .010$, and crosses, $F(1, 30) = 9.26$, $p = .005$; and a significant effect of day for crosses, $F(1, 30) = 4.98$, $p = .033$.

At P24–25 (Figures 6A–6D), there were significant Task \times Location interactions for all four dependent measures; latency, $F(1, 30) = 18.45$, $p < .001$; time, $F(1, 30) = 33.13$, $p < .001$; proximity, $F(1, 30) = 25.15$, $p < .001$; crosses, $F(1, 30) = 12.75$, $p = .001$. Across both days of testing, rats in the direction task

reached the target region faster than the nontarget region, $p < .001$, spent more time in the target region than the nontarget region, $p < .001$, swam closer to the target location than the nontarget location, $p < .001$, and crossed the target location more often than the nontarget location, $p < .001$. Rats in the place task showed no discrimination between the target and nontarget region/location, $ps > .191$. There were also significant effects of task for time, $F(1, 30) = 14.13$, $p = .001$, and crosses, $F(1, 30) = 4.92$, $p = .034$; and significant effects of location for all dependent measures; latency, $F(1, 30) = 31.82$, $p < .001$; time, $F(1, 30) = 36.59$, $p < .001$; proximity, $F(1, 30) = 20.50$, $p < .001$; crosses, $F(1, 30) = 24.31$, $p < .001$.

At P26–27 (Figures 7A–7D), there were significant effects of location for all four dependent measures; latency, $F(1, 30) = 18.23$, $p < .001$; time, $F(1, 30) = 26.17$, $p < .001$; proximity, $F(1, 30) = 20.00$, $p < .001$; crosses, $F(1, 30) = 41.90$, $p < .001$.

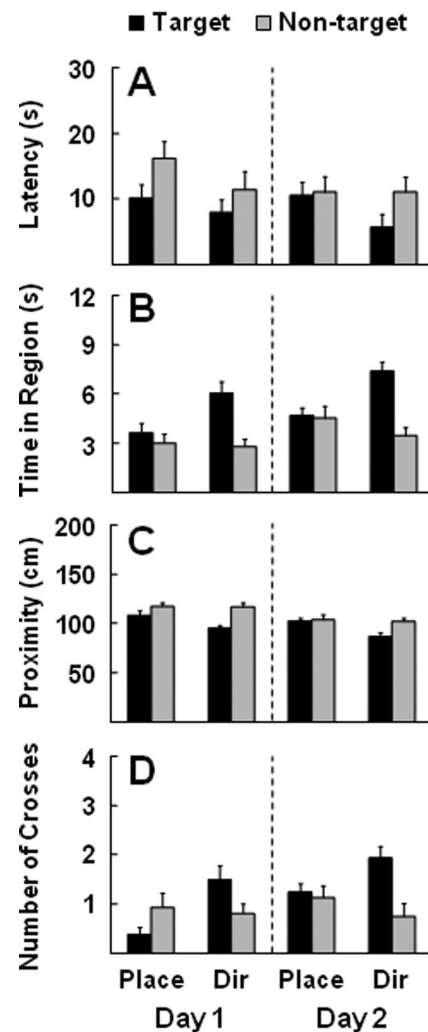


Figure 4. At P20–21, rats in the direction task preferred the target over the nontarget region/location during the probe trials, but rats in the place task did not discriminate between regions/locations. (A) Latency to reach critical regions. (B) Time spent in the critical regions. (C) Average proximity of swim path from the critical locations. (D) Number of times the critical locations were crossed.

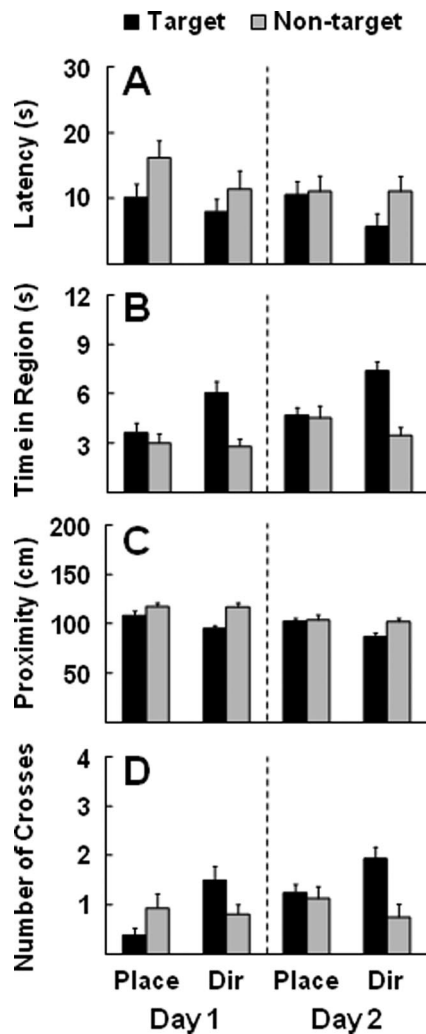


Figure 5. At P22–23, rats in the direction task preferred the target over the nontarget region/location during the probe trials, but rats in the place task did not discriminate between regions/locations. (A) Latency to reach the critical regions. (B) Time spent in the critical regions. (C) Average proximity of swim path from the critical locations. (D) Number of times the critical locations were crossed.

Across both days of testing, both rats in the direction task and rats in the place task reached the target region faster than the nontarget region, $ps < .014$, spent more time in the target region than the nontarget region, $ps < .044$, swam closer to the target location than the nontarget location, $ps < .014$, and crossed the target location more often than the nontarget location, $ps < .001$. The presence of significant Task \times Location interactions for time, $F(1, 30) = 9.25$, $p = .005$, and crosses, $F(1, 30) = 7.85$, $p = .009$, however, indicates that rats in the direction task showed greater discrimination between the target and nontarget region/location than rats in the place task considering these measures. There were also significant effects of day for time, $F(1, 30) = 5.39$, $p = .027$, and proximity, $F(1, 30) = 6.06$, $p = .020$; and significant effects of task for time, $F(1, 30) = 10.14$, $p = .003$, and crosses, $F(1, 30) = 10.52$, $p = .003$.

Discussion

We examined the development of directional responding and place navigation in two variants of the Morris water task among male and female rats aged 18 to 27 days. In the place variant of the task, rats were trained to navigate to a precise spatial location to find a hidden escape platform regardless of the position of the pool in the testing room. In the direction variant of the task, rats were trained to navigate in a particular direction to find a hidden escape platform regardless of the position of the pool. We found that at 18 to 19 days of age, rats in both the place and direction tasks exhibited long latencies to reach the platform during training and no discrimination between the trained platform location and an arbitrary, untrained location during the probe trials. Between 20 and 25 days of age, rats in the direction task displayed shorter latencies to reach the platform during training compared to rats in the place task. Furthermore, rats in the direction task selectively

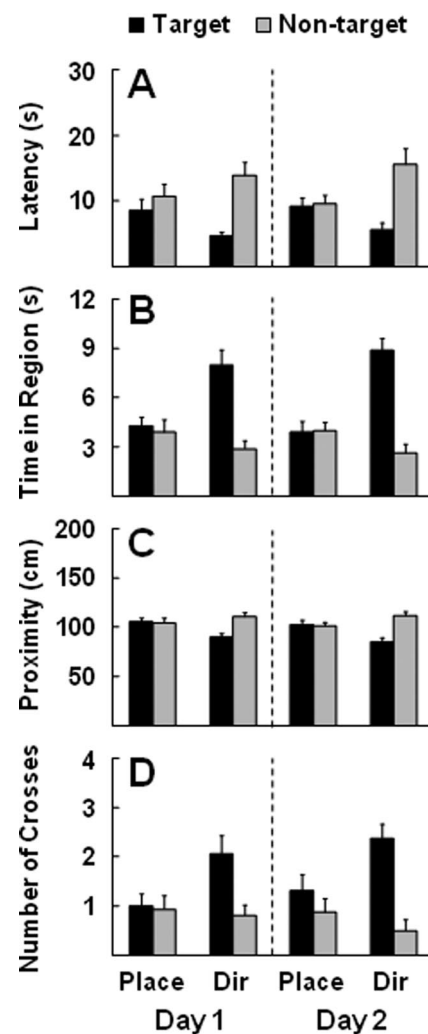


Figure 6. At P24–25, rats in the direction task preferred the target over the nontarget region/location during the probe trials, but rats in the place task did not discriminate between regions/locations. (A) Latency to reach the critical regions. (B) Time spent in the critical regions. (C) Average proximity of swim path from the critical locations. (D) Number of times the critical locations were crossed.

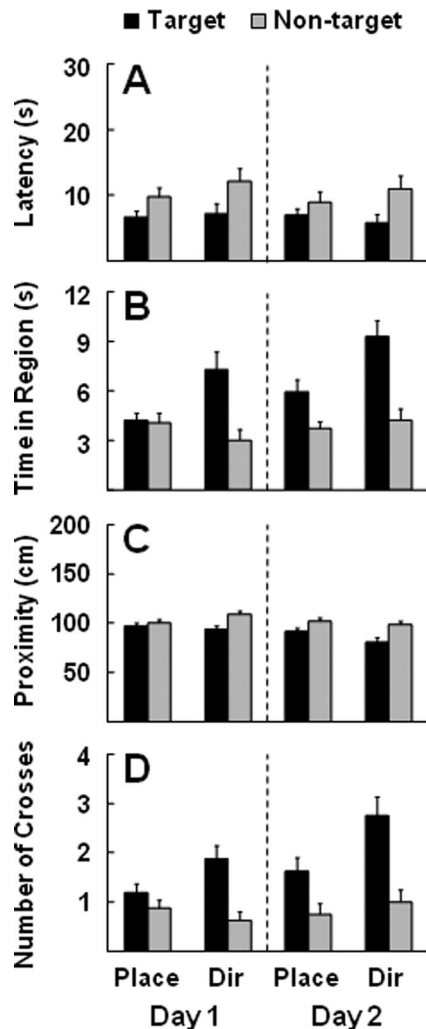


Figure 7. At P26–27, both rats in the direction task and rats in the place task preferred the target over the nontarget region/location during the probe trials. (A) Latency to reach the critical regions. (B) Time spent in the critical regions. (C) Average proximity of swim path from the critical locations. (D) Number of times the critical locations were crossed.

searched for the platform at its trained location during the probe trials, but rats in the place task did not discriminate between trained and untrained locations. At 26 to 27 days of age, rats in the direction task and rats in the place task selectively searched for the platform at its trained location during the probe trials, although rats in the direction task continued to exhibit shorter latencies to reach the platform during training compared to rats in the place task. These results indicate that directional responding and place navigation can be developmentally dissociated in the rat, with directional responding emerging around 20 to 21 days of age but place navigation not emerging until 26 to 27 days of age.

Previous developmental studies have sought to determine whether cued navigation can be developmentally dissociated from place navigation by using standard cued and hidden versions of the Morris water task. In the majority of these studies (cf. Brown & Whishaw, 2000), ability to solve the cued platform version was

found to emerge around 17 to 18 days of age, whereas ability to solve the hidden platform version was found to emerge around 20 to 21 days of age (Akers & Hamilton, 2007; Rudy & Paylor, 1988; Rudy et al., 1987). Because rats tend to solve the standard hidden platform version of the Morris water task via directional responding and not true place navigation (Akers et al., 2007; Hamilton et al., 2008, 2007), however, it is likely that these previous developmental studies did not assess the ontogeny of true place navigation but rather assessed the ontogeny of directional responding. This likelihood is strengthened by the observation that the age at which learning in the standard hidden platform task was found to emerge in these previous studies (Akers & Hamilton, 2007; Rudy & Paylor, 1988; Rudy et al., 1987) is in precise agreement with the age at which learning in the direction task was found to emerge in the present study—at 20 to 21 days of age.

According to this view, therefore, the ontogeny of cued navigation and directional responding have been described by previous studies, but the development of true place navigation has, until now, been left unexplored. By using variants of the Morris water task that disambiguate directional responding and place navigation, we found that ability to perform directional responses emerges at 20 to 21 days of age, but ability to place navigate does not emerge until 26 to 27 days of age. At this later age, however, rats' ability to perform the place task was not as robust as ability to perform the direction task, evidenced by longer latencies to reach the platform during training and less discrimination between trained and untrained locations during the probe trials. This relative difficulty with which rats learn to solve the place task is unlikely to diminish with age, as rats in adulthood show a similar disadvantage in the place task as compared to the direction task in terms of both longer latencies during training and less discrimination between trained and untrained locations during probe trials (Hamilton et al., 2008).

Reports of sex differences in spatial learning in the rat have been inconsistent, but the majority of studies report that adult males exhibit better spatial learning than adult females in the Morris water task (Jonasson, 2005). Whether a sex difference in spatial learning also exists among young rats has not yet been determined. Although several previous developmental water task studies have included both male and female rats (Akers et al., 2007; Akers & Hamilton, 2007; Brown & Whishaw, 2000; Carman et al., 2002; Carman & Mactutus, 2001; Schenk, 1985), sex differences were either not found or not explicitly tested. In the present study, we tested for possible sex differences in the ontogeny of directional responding and place navigation and found two instances of sex differences. First, among rats aged 18 to 19 days, females found the platform faster than males on the first day of training in the place task. Because rats were not able to actually solve the task at this age, however, this difference between males and females is unlikely due to a difference in learning ability. Second, regardless of task, females exhibited a greater reduction in latency to reach the platform across training days compared to males, but only at 24 to 25 days of age. Therefore, we found little, if any, evidence of sex differences in spatial learning across the ages tested here.

Our finding that the emergence of place navigation lags behind that of directional responding leads us to consider possible explanations for this developmental dissociation. Importantly, the methodology used in this study serves to rule out several factors that could potentially contribute to different developmental time

courses for the two types of spatial navigation. First, because the average distance between the release points and the platform location were the same for direction and place tasks during both training and probe trials, motor demands were identical for the two tasks. Second, the water temperature and rats' body temperatures were regulated to the same extent for both tasks, thus preventing differences between tasks in motivational demands. Third, the same distal cue environment was used for both tasks, thereby reducing the likelihood that sensory demands differed between tasks, although it may have been possible for rats to solve the direction task by relying on a smaller number of distal cues compared to the place task. Overall, therefore, it is unlikely that these noncognitive factors could explain the developmental dissociation of place navigation and directional responding.

One possible explanation for why rats are able to solve the direction task several days earlier in development than the place task is that the place task is more difficult than the direction task. Numerous studies have demonstrated that young rats learn relatively simple tasks soon after the required sensory or motor systems become functional, but that they do not learn relatively complex tasks until days or weeks thereafter (Bachevalier & Beauguard, 1993; Dumas, 2005; Stanton, 2000). In terms of spatial tasks, previous studies among adult rats indicate that tasks requiring place responses are generally more difficult to learn than tasks requiring direction responses (Blodgett, McCutchan, & Mathews, 1949; Hamilton et al., 2008; Skinner et al., 2003; Stringer, Martin, & Skinner, 2005). Thus, future studies examining differences in the ontogeny of place navigation and directional responding could utilize a task in which the level of difficulty is matched between place and direction variants. For instance, adult rats learn to perform place responses as easily as direction responses in dry-land mazes provided that the release locations for the different apparatus positions are easily discriminated (Horne, Martin, Harley, & Skinner, 2007; Skinner et al., 2003). The use of such dry-land mazes, however, may not be feasible for developmental studies seeking to determine the precise day of development on which certain navigational abilities emerge, as several days are necessary to train rats to consistently perform correct responses.

Another explanation for the late development of place navigation relative to directional responding may be because the two types of spatial navigation have separate neurobiological bases that exhibit different rates of maturation. One possibility is that the hippocampal formation, which encodes information regarding an animal's location in space (O'Keefe & Nadel, 1978), matures later than the head direction cell system, which encodes information regarding an animal's directional heading (Taube, 1998). Indeed, one study found that whereas locational firing of hippocampal cells is not adult-like until around 50 days of age, directional firing of cingulate cells is adult-like as early as 30 days of age (Martin & Berthoz, 2002). Because both place and direction responding in a dry-land T maze are impaired by hippocampal lesions (Stringer et al., 2005), however, another possibility is that the two types of spatial navigation depend on subtle differences in hippocampal anatomy or physiology that exhibit different rates of development across the first few postnatal months. For instance, granule neurons in the dentate gyrus undergo a period of dendritic remodeling between 14 and 60 days of age, including both increases and decreases in dendritic length and an overall increase in spine

density (Rahimi & Claiborne, 2007). Inhibitory synaptic transmission continues to develop between 14 and 45 days of age, indicated by a gradual increase in GABA_B receptor-mediated postsynaptic currents (Nurse & Lacaille, 1999). Furthermore, dentate gyrus- and CA1-generated theta-frequency activity does not become adult-like until around 23 days of age (LeBlanc & Bland, 1979). Thus, our finding of a developmental dissociation between directional responding and place navigation provides further impetus to the investigation of potential differences in the neuroanatomy or neurophysiology underlying these two types of spatial navigation.

References

- Akers, K. G., Candelaria, F. T., & Hamilton, D. A. (2007). Prewanling rats solve the Morris water task via directional navigation. *Behavioral Neuroscience*, *121*, 1426–1430.
- Akers, K. G., & Hamilton, D. A. (2007). Comparison of developmental trajectories for place and cued navigation in the Morris water task. *Developmental Psychobiology*, *49*, 553–564.
- Bachevalier, J., & Beauguard, M. (1993). Maturation of medial temporal lobe memory functions in rodents, monkeys, and humans. *Hippocampus*, *3*, 191–202.
- Blodgett, H. C., McCutchan, K., & Mathews, R. (1949). Spatial learning in the T maze: The influence of direction, turn, and food location. *Journal of Experimental Psychology*, *39*, 800–809.
- Brown, R. W., & Kraemer, P. J. (1997). Ontogenetic differences in retention of spatial learning tested with the Morris water maze. *Developmental Psychobiology*, *30*, 329–341.
- Brown, R. W., & Whishaw, I. Q. (2000). Similarities in the development of place and cue navigation by rats in a swimming pool. *Developmental Psychobiology*, *37*, 238–245.
- Carman, H. M., Booze, R. M., & Mactutus, C. F. (2002). Long-term retention of spatial navigation by preweanling rats. *Developmental Psychobiology*, *40*, 68–77.
- Carman, H. M., & Mactutus, C. F. (2001). Ontogeny of spatial navigation in rats: A role for response requirements? *Behavioral Neuroscience*, *115*, 870–879.
- Dumas, T. C. (2005). Late postnatal maturation of excitatory synaptic transmission permits adult-like expression of hippocampal-dependent behaviors. *Hippocampus*, *15*, 562–578.
- Gallagher, M., Burwell, R., & Burchinal, M. (1993). Severity of spatial learning impairment in aging: Development of a learning index for performance in the Morris water maze. *Behavioral Neuroscience*, *107*, 618–626.
- Hamilton, D. A., Akers, K. G., Johnson, T. E., Rice, J. P., Candelaria, F. T., Weisend, M. P., et al. (2008). The relative influence of place and direction in the Morris water task. *Journal of Experimental Psychology: Animal Behavior Processes*, *34*, 31–53.
- Hamilton, D. A., Akers, K. G., Weisend, M. P., & Sutherland, R. J. (2007). How do room and apparatus cues control navigation in the Morris water task? Evidence for distinct contributions to a movement vector. *Journal of Experimental Psychology: Animal Behavior Processes*, *33*, 100–114.
- Horne, M. R., Martin, G. M., Harley, C. W., & Skinner, D. M. (2007). Where am I? Distal cue use requires sensitivity to start location change in the rat. *Journal of Experimental Psychology: Animal Behavior Processes*, *33*, 92–99.
- Iivonen, H., Nurminen, L., Harri, M., Tanila, H., & Puolivali, J. (2003). Hypothermia in mice tested in Morris water maze. *Behavioural Brain Research*, *141*, 207–213.
- Jonasson, Z. (2005). Meta-analysis of sex differences in rodent models of learning and memory: A review of behavioral and biological data. *Neuroscience and Biobehavioral Reviews*, *28*, 811–825.
- Kraemer, P. J., & Randall, C. K. (1995). Spatial learning in preweanling rats trained in a Morris water maze. *Psychobiology*, *23*, 144–152.

- LeBlanc, M. O., & Bland, B. H. (1979). Developmental aspects of hippocampal electrical activity and motor behavior in the rat. *Experimental Neurology*, 66, 220–237.
- Loewen, I., Wallace, D. G., & Whishaw, I. Q. (2005). The development of spatial capacity in piloting and dead reckoning by infant rats: Use of the huddle as a home base for spatial navigation. *Developmental Psychobiology*, 46, 350–361.
- Martin, P. D., & Berthoz, A. (2002). Development of spatial firing in the hippocampus of young rats. *Hippocampus*, 12, 465–480.
- Morris, R. G. M. (1981). Spatial localization does not require the presence of local cues. *Learning and Motivation*, 12, 239–260.
- Morris, R. G. M. (1984). Developments of a water-maze procedure for studying spatial-learning in the rat. *Journal of Neuroscience Methods*, 11, 47–60.
- Moser, E. I., & Anderson, P. (1994). Conserved spatial learning in cooled rats in spite of slowing of dentate field potentials. *Journal of Neuroscience*, 14, 4458–4466.
- Nurse, S., & Lacaille, J. C. (1999). Late maturation of GABA-B synaptic transmission in area CA1 of the rat hippocampus. *Neuropharmacology*, 38, 1733–1742.
- O'Keefe, J., & Nadel, L. (1978). *The hippocampus as a cognitive map*. Oxford, England: Oxford University Press and Clarendon.
- Rahimi, O., & Claiborne, B. J. (2007). Morphological development and maturation of granule neuron dendrites in the rat dentate gyrus. *Progress in Brain Research*, 163, 167–181.
- Rauch, S. L., & Raskin, L. A. (1984). Cholinergic mediation of spatial memory in the preweanling rat: Application of the radial arm maze paradigm. *Behavioral Neuroscience*, 98, 35–43.
- Rauch, T. M., Welch, D. I., & Gallego, L. (1989). Hypothermia impairs performance in the Morris water maze. *Physiology and Behavior*, 46, 315–320.
- Rossier, J., & Schenk, F. (2003). Olfactory and/or visual cues for spatial navigation through ontogeny: Olfactory cues enable the use of visual cues. *Behavioral Neuroscience*, 117, 412–425.
- Rudy, J. W., & Paylor, R. (1988). Reducing the temporal demands of the Morris place-learning task fails to ameliorate the place-learning impairment of preweanling rats. *Psychobiology*, 16, 152–156.
- Rudy, J. W., Stadler-Morris, S., & Albert, P. (1987). Ontogeny of spatial navigational behaviors in the rat: Dissociation of “proximal”- and “distal”-cue-based behaviors. *Behavioral Neuroscience*, 101, 62–73.
- Schenk, F. (1985). Development of place navigation in rats from weaning to puberty. *Behavioral and Neural Biology*, 43, 69–85.
- Skinner, D. M., Etchegary, C. M., Ekert-Maret, E. C., Baker, C. J., Harley, C. W., Evans, J. H., et al. (2003). An analysis of response, direction, and place learning in an open field and T maze. *Journal of Experimental Psychology: Animal Behavior Processes*, 29, 3–13.
- Stanton, M. E. (2000). Multiple memory systems, development and conditioning. *Behavioral Brain Research*, 110, 25–37.
- Stringer, K. G., Martin, G. M., & Skinner, D. M. (2005). The effects of hippocampal lesions on response, direction, and place learning in rats. *Behavioral Neuroscience*, 119, 946–952.
- Taube, J. S. (1998). Head direction cells and the neurophysiological basis for a sense of direction. *Progress in Neurobiology*, 55, 225–256.
- Tonkiss, J., Shultz, P., & Galler, J. R. (1993). Long-Evans and Sprague-Dawley rats differ in their spatial navigation performance during ontogeny and at maturity. *Developmental Psychobiology*, 25, 567–579.

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Candidates should be members of Division 38 and of APA, and should be available to start receiving manuscripts in 2010 to prepare issues to be published in 2011. Division 38 encourages participation by members of underrepresented groups and would welcome such nominees. Self-nominations are also encouraged.

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