



Motor activity (exploration) and formation of home bases in mice (C57BL/6) influenced by visual and tactile cues: Modification of movement distribution, distance, location, and speed

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Abstract

The motor activity of mice in tests of “exploration” is organized. Mice establish home bases, operationally defined as places where they spend long periods of time, near physical objects and nesting material from which they make excursions. This organization raises the question of the extent to which mouse motoric activity is modulated by innate predispositions versus environmental influences. Here the influence of contextual cues (visual and tactile) on the motor activity of C57BL/6 mice was examined: (1) on an open field that had no walls, a partial wall, or a complete wall, (2) in the presence of distinct visual cues, room cues, or in the absence of visual cues (infrared light), and (3) in the presence of configurations of visual and tactile cues. Mice were generally less active in the presence of salient cues and formed home bases near those cues. In addition, movement speed, path distribution, and the number and length of stops were modulated by contextual cues. With repeated tests, mice favored tactile cues over visual cues as their home base locations. Although responses to cues were robust over test days, conditioning to context was generally weak. That the exploratory behavior of mice is affected by experience and context provides insights into performance variability and may prove useful in investigating the genetic and neural influences on mouse behavior.

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1. Introduction

The interest in using mice for the study of spatial behavior has stimulated the development of tests and measures that are species appropriate. Unconstrained tests of activity or “exploration” seem ideal (see [24] for an early review of exploration) in this respect because they allow spontaneous expression of species-specific behavior and thus can provide insights into the genetic influences on behavior [5,8,17–19,21]. Nevertheless, initial neurobehavioral research suggested that the exploratory behavior of rodents is stochastic [12,23] and more recent reports

that mice in relatively featureless environments fail to restrict their movements spatially seems confirmatory [7,15]. Nevertheless, mice do show organized behavior if the complexity of the test environment is increased. For example, mice readily establish home bases, locations operationally defined as places that they spend distinctive periods of time and from which they make excursions, near physical objects [8,9] and nesting materials [15].

That a single object in a relatively featureless environment can organize the behavior of mice raises questions concerning the extent to which a testing apparatus and its ambient environment can influence mouse motor activity. One approach recommends the use of standardized testing procedures [4,29,30], but even in such conditions not all intra-apparatus and distal cues are considered experimental variables. Another view suggests that, at least for some tests, the influence of the

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environment is minimal [8,18,19,21], but again ambient cues may not be treated as experimental variables. Additionally, for many studies in which exploratory activity is used simply as an assay of motor integrity, the apparatus and contextual cues are generally not featured as experimental variables [2,28]. Nevertheless, it is clear that if central questions concerning genetic and environmental contributions to the spatial behavior of mice are to be investigated, the extent to which context influences behavioral organization requires examination.

The purpose of the present study was to investigate whether experience and ambient context of a test apparatus can influence mouse exploratory activity. The core apparatus was a circular table without walls [3], to which tactile and visual cues could be added. It was expected that activity would display “habituation” with repeated testing, suggesting that animals do learn about their environment during exploration [24]. Additionally, on the basis of previous work with rats, it was expected that visual cues should modify the organization of the activity of the animals [3,16], although some recent studies have suggested that the influence of visual cues on mouse behavior is minimal [11,26]. Because most previous studies have used test containers with walls, toward which animals are prone to display thigmotaxic behavior, the present study investigated both the influence of thigmotaxic behavior on the organization of exploratory activity as well as the influence of thigmotaxic responses to visual cues. Finally, in order to examine mnemonic influences on the organization of exploration, mice were given probe tests in which salient cues were removed [16]. Dependent measures were movement location, distance, and movement speed, as well as the location, duration, and frequency of stops.

2. Materials and methods

2.1. Subjects

Adult male C57BL/6 mice (*Mus musculus domesticus*) were used as subjects. The animals were housed in groups of three in Plexiglas cages and were kept on a 12/12h light/dark cycle (8:00–20:00) with food and water provided ad libitum. Behavioral testing occurred during the light cycle. All procedures were approved by the University of Lethbridge Animal Care Committee, which follows the standards set by the Canadian Council on Animal Care.

2.2. Open fields

Two open fields were used. (1) Open table: a large wooden circular table (Fig. 1, left) measuring 155 cm in diameter without walls. (2) Walled table: the walled table was a fiber glass container (Fig. 1, right) measuring 155 cm in diameter and with walls that were 40 cm in height. Both tables were painted white and were elevated 64 cm from the floor. The tables were mounted on ball-bearings so that they could be rotated after each test to each mouse. In addition, they were wiped down with soap and water after testing each mouse. Each apparatus was located in a large room in which a number of visual cues were present including a door, a light switch, thermostat, and paper towel dispenser on the wall. Two conspicuous objects, a counter and bookcase, were covered with white sheets to render them less salient [16].

2.3. Visual cue

The visual cue was a large black box (43 × 46 × 62 cm high) placed 15 cm away from the edge of the open table with its bottom level with the top of the table (Fig. 1, left). In the enclosed table, a black cue card (46 × 62 cm high) served as the visual cue and was attached to the inside of the wall (Fig. 1, right). Both cues remained in the same location for the duration of the experiments.

2.4. Tactile cue

A removable white wall (56 × 40 cm high) made of laminated bristle board was placed along the edge of the open table (Fig. 1, left). The wall was located in the quadrant opposite the visual cue and remained in the same location throughout the relevant experiment. Because the room wall was painted white like the removable wall, it was unlikely to have been seen as a prominent visual cue by the mice [27]. The wall was wiped down with soap and water after testing each mouse.

2.5. Movement tracking and analysis

Each session was video taped by an overhead camera attached to a digital camcorder. AccuTrak software (AccuScan Instruments, Inc. Columbus, OH, 43228, USA) was used to determine the mouse’s position in a Cartesian coordinate system

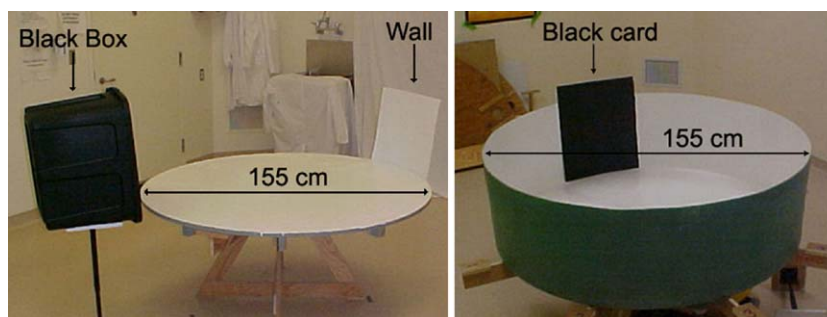


Fig. 1. The apparatus consisted of a wooden table (left) and a fiberglass swimming pool (right) both measuring 155 cm in diameter. Cues consisted of a black box or wall for the table and a black card on the wall for the swimming pool.

at a sampling rate of 30 Hz. The AccuTrak system automatically tracks the midline of a mouse's back at the level of the forelimbs by selecting one pixel per frame of the digital computer file. The x - and y -coordinates were subjected to further analysis using a custom computer program written in the C++ programming language. Mouse movements and movement patterns were divided into components that were based on a previously described ethogram [3,10,14]. Additional behavioral measures made were:

- 1.) *Distance*. The paths of mice were reconstructed and measured for total length (cm).
- 2.) *Percent area*. The surface of the table-top was divided into 900 individual squares. The percent area was derived using the following formula: Percent area = [(# of squares transected)/(total # of squares)] × 100. Percent area distinguishes mice that traveled equal distances, but visited few versus many regions of the table.
- 3.) *Stops*. Stops were characterized by speeds of 0.0 m/s lasting at least 1 s or greater. Stops were grouped into a filter bin according to the amount of time they occupied. Bin times consisted of: 1–2, 3–10, 11–30, and 31+ s.
- 4.) *Segment preference*. The circular apparatus was divided into 16 pie shaped segments and time, distance, and the number of stops in each segment was calculated.
- 5.) *Speed profiles*. A profile of the animals speeds were made by filtering the x - and y -coordinates into filter bins defined by the speeds that they occupy. Bin speeds consisted of: 1–20, 20–40, and 40+ cm/s, and would be comparable to gears one, two and three of Draai et al. [6]. For analysis, the

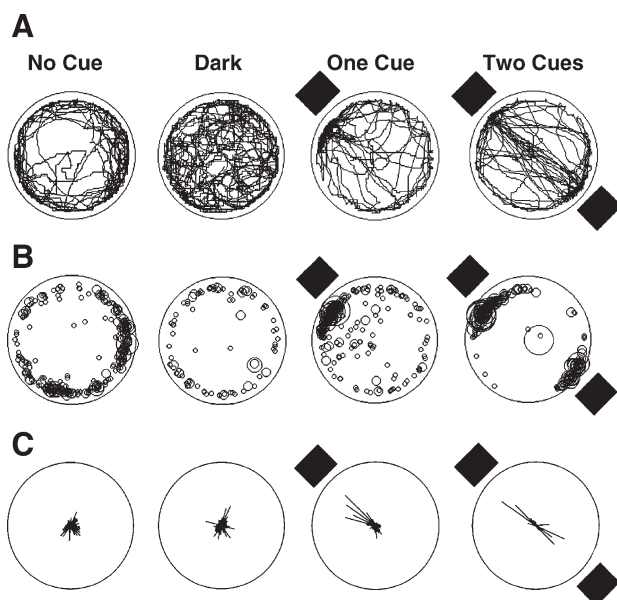


Fig. 2. (A) Paths, (B) stops, and (C) polar histograms for a representative mouse for the No Cue, Dark, One Cue, and Two Cue groups. Stop duration is represented by the diameter of the circles: 0–2, 3–10, 11–30, and 30+ s. In the polar histograms, the black lines represent the percent time in each 1/16 pie shaped segment of the open field. The black squares represent the visual cue locations.

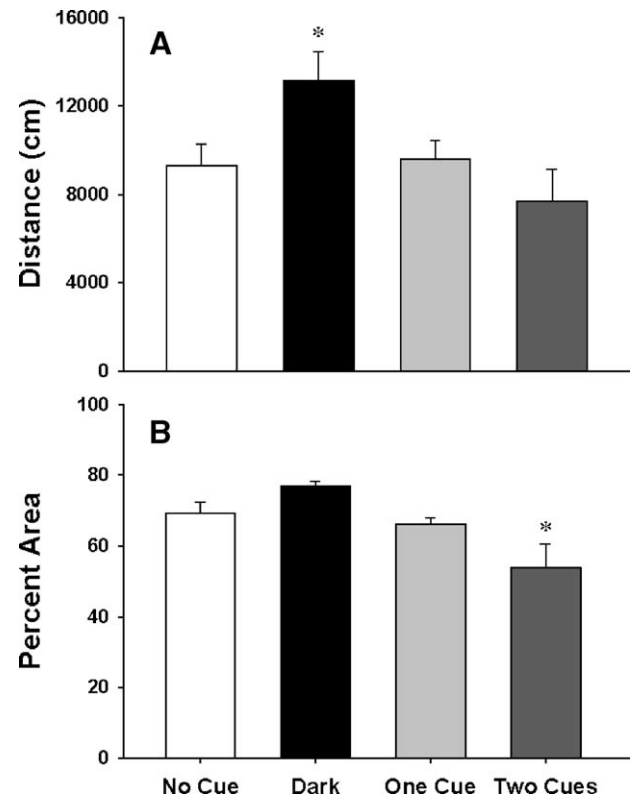


Fig. 3. (A) Distance (mean ± S.E.M.) traveled and (B) percent area (mean ± S.E.M.) of the table traversed by the No Cue, Dark, One Cue, and Two Cue groups (* $P < 0.05$).

proportion of progressions occurring at each of the three speeds was compared.

2.6. Statistical analysis

The results were analyzed using analysis of variance of testing group and repeated measures on dependent variables with Fisher's PLSD post hoc tests [34].

3. Procedures

3.1. Experiment 1: exploratory movements in relation to prominent visual cues

The experiment examined the influence of a prominent visual cue on exploratory behavior. At the start of a session, a mouse was brought into the testing room and was placed in the center of the table without walls (Fig. 1, left). The experimenter left the room after placing the mouse at the center of the apparatus. Each exploratory session lasted 30 min in which the animal was free to move around upon the table. At the end of the session, the mouse was removed from the apparatus and returned to its home cage. Twenty four mice were divided into groups of six. Each group was designated to a specific testing condition outlined below:

- 1.) *Two Cues*. In this test, two black boxes were positioned near the table in quadrants directly opposite each other.

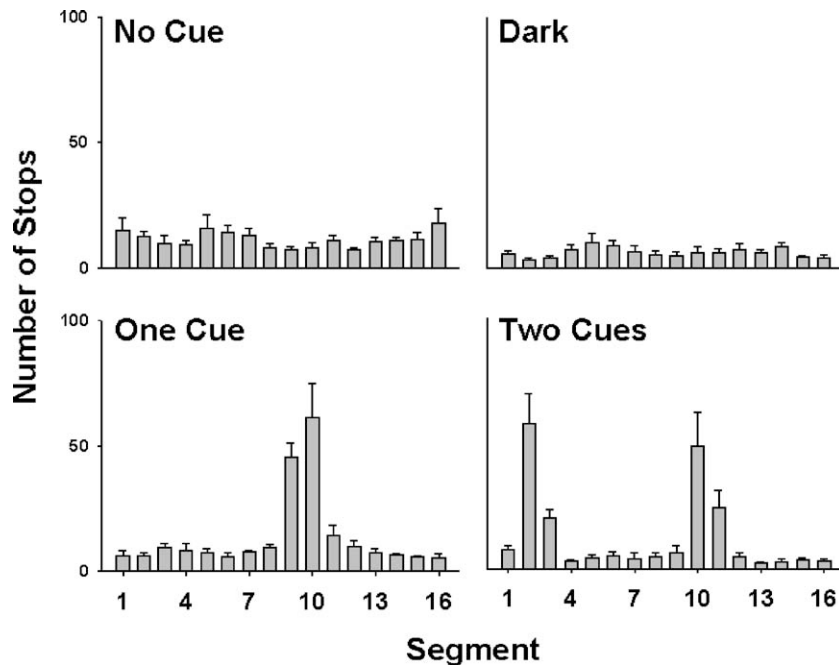


Fig. 4. The number of stops (mean±S.E.M.) as a function of pie shaped segments (16 segments) for mice in the No Cue, Dark, One Cue, and Two Cue groups. Note: peak stopping locations occur at segments where the cues were located (segment 10 for one cue and segments 2 and 10 for two cues).

- 2.) *One Cue*. A single black box was positioned near the table.
- 3.) *No Cue*. Neither visual cue (black box) was present.
- 4.) *Dark*. The testing room lights were turned off, thus eliminating visual cues. The testing room was light proof for dark testing. Infrared light was reflected from two emitters onto the room walls to produce even lighting over the table. The experimenter wore infrared goggles in order to place the animals on the circular table.

3.2. Experiment 2: exploratory movements in relation to a prominent visual cue with surrounding walls present or absent

The experiment examined the influence of a prominent visual cue on exploration when surrounding white walls were either present or absent. Twelve mice were divided into two groups of six. Test conditions for the respective groups were:

- 1.) *No Wall*. Mice were placed on the open table for 30 min (Fig. 1, left). The prominent visual cue was a black box placed near the edge of the table (Fig. 1, left).
- 2.) *Wall*. Mice were placed in the walled table for 30 min (Fig. 1, right). The prominent visual cue was a black cue card attached to the inside of the pool wall (Fig. 1, right).

The procedure was similar to experiment 1, but each 30 min session for each mouse was repeated daily for five days. The visual cues remained in the same location on each of the first four testing days. On a probe given on the fifth testing day, the prominent visual cue was removed from the room prior to the mice being placed in the apparatus.

3.3. Experiment 3: exploratory movements in relation to a prominent visual and tactile cue

This experiment examined the influence of a prominent visual cue and prominent tactile cue on exploratory behavior. Six mice were placed singly in the center of the open table (Fig. 1, left). The prominent visual cue (black box) was placed near the table and the tactile cue (white wall) was attached to the table in the quadrant opposite the visual cue (Fig. 1, left). Each session lasted 30 min and was repeated daily for five days, except on a probe day given on the fifth day, the prominent visual and tactile cues were removed from the testing room.

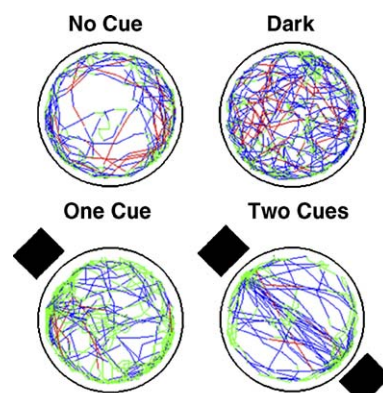


Fig. 5. The speed of progressions between stops for representative mice in the No Cue, Dark, One Cue, and Two Cue groups. Each color designates a particular speed (Green=1–20 cm/s, Blue=20–40 cm/s, Red=40+ cm/s). The black squares equal the visual cue location. Note: higher speed progressions occur in the dark and no cue conditions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. Results

4.1. Experiment 1: exploratory movements in relation to prominent visual cues

4.1.1. Spatial distribution of movement

Fig. 2 illustrates typical open field activity of a representative mouse from each group and shows that paths were influenced by the testing condition. The mice were more active and traversed a wider region of the table in the dark than in the light. When cues were present near the table, travel paths were shorter and tended to converge in regions of the table near the cues (Fig. 2A). Stop locations are illustrated in Fig. 2B, with each circle representing a stop and the size of the circle representing duration. Short stops tended to be dispersed around the edge of the table in the dark and in the light when no cues were present. Both short stops and long stops occurred when cues were present and most of these stops were located proximal to the cues. The vectors (16 vectors representing 16 pie segments of the table) in Fig. 2C illustrates the quadrant of the table in which mice spent their time. In the absence of visual cues in the dark and light the mice displayed no preference, while when cues were present the mice preferred regions adjacent to the cues.

4.1.2. Path length and distribution

Fig. 3A illustrates comparative path lengths and the distribution of trips on the table. Significant group comparisons, $(3,20)=3.912$, $P<0.05$ and follow-up Fisher's tests on group means, indicated that the mice were more active in the dark than they were in the other three cue conditions. Differences between the other conditions were not significant, although distance traveled was less in the Two Cues condition. Fig. 3B illustrates

the dispersion of trips on the table. Significant group comparisons, $F(3,20)=6.356$, $P<0.01$, and follow-up tests on the group means indicated that the distribution of trips were more restricted in the Two Cue condition. Although the percent area increased from the One Cue to No Cue to the Dark condition, these mean differences were not significant.

4.1.3. Regional preference

Percent time was measured in each of the 16 pie shaped segments of the table. The ANOVA that compared testing condition as a function of percent time in the pie segments gave a significant result, $F(45,300)=5.762$, $P<0.001$. Individual analyses on each of the cue conditions gave no significant effects of pie segments in the No Cue and Dark conditions, as the mice spend approximately the same length of time in each segment (see the representative vectors in Fig. 2C). The effects of segments were significant for the One Cue and Two Cue conditions, and as is illustrated in Fig. 2C, the mice spent more time in the pie segments adjacent to the cues.

A similar pattern of results was obtained for segments of the table in which the mice stopped (Fig. 4). An ANOVA that compared where the mice stopped gave a significant main effect of Group, $F(3,20)=10.727$, $P<0.001$, and a significant Group by Segment interaction, $F(45,300)=9.793$, $P<0.001$. Follow up tests on each condition indicated that there were no significant differences in the number of stops in the No Cue and Dark conditions, but there were significant effects of pie segments in the One Cue and Two Cue conditions. As is illustrated in Fig. 4, the highest number of stops was made in the segments of the table adjacent to the cue in the One Cue condition and with the highest number stops adjacent to both cues in the Two Cue condition.

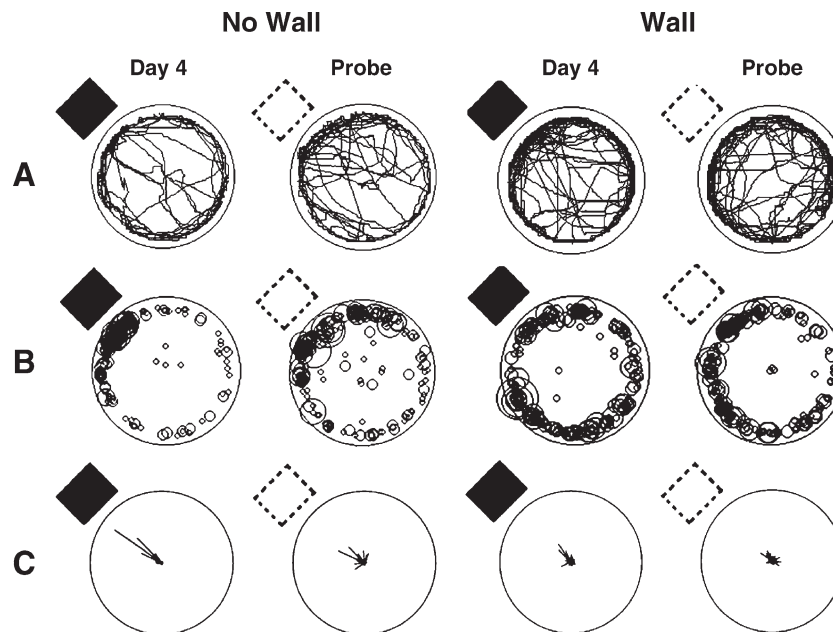


Fig. 6. (A) Paths, (B) stops, and (C) polar histograms from representative mice in the No Wall and Wall groups on Day 4 and on a Probe test given the following day with the cues removed. Stop duration is represented by the diameter of the circles: 0–2, 3–10, 11–30, and 30+ s. In the polar histograms, the black lines represent the percent time in that segment (of 16 segments) of the open field. The black square represents the visual cue location and the dotted square is its previous location. Note: the preferences for the region of the table adjacent to the cue in the No Wall condition versus the relative absence of a preference in the Wall condition.

4.1.4. Speed

Fig. 5 illustrates the speed profiles of representative mice from each testing condition. Paths were reconstructed to illustrate three levels of predefined speeds (Green=1–20 cm/s, Blue=20–40 cm/s, Red=40+ cm/s). An ANOVA on the number of speed progressions in each of the conditions gave no significant condition differences. There was, however, a significant interaction between progressions at different speeds in the different cue conditions, Group by Speed: $F(6,40)=16.7$, $P<0.001$. As is illustrated in Fig. 5, in the Two Cue and One Cue testing conditions, mice generally progressed at slow speeds (Green) especially near the visual cue and along the edge of the table, while mice in No Cue and Dark conditions generally displayed more progressions featuring mid to high speeds. In all groups, slower speeds tended to occur along the edges of the table.

4.2. Experiment 2: exploratory movements in relation to a prominent visual cue with surrounding walls present or absent

4.2.1. Spatial distribution of movement

The presence of a wall around the table suppressed preferences for regions adjacent to visual cues (Fig. 6). Fig. 6A illustrates that without a wall (No Wall), movements converged in the region of the visual cue, while in the walled condition (Wall) movements were distributed around the edge of the wall with little apparent influence of the prominent visual cue. Similarly, in the absence of a wall, stops were mainly adjacent to a visual cue, whereas with a wall, stops were distributed adjacent to the wall without being influenced by the cue (Fig. 6B). Vectors representing the total time in one of the 16 segments of the table also indicated that mice spent a majority of their time near a visual cue when no wall was present, but displayed no segmental bias when the wall was present (Fig. 6C). This pattern of results was obtained over four days of testing, although there was a general decline in locomotor activity across test days. On the Probe trial, for which the visual cues were removed, the mice in the Wall condition similarly failed to display a regional preference whereas the mice in the No Wall group preferred a location adjacent to the visual cues previous location, although the preference was weaker than it was when the cue was present.

4.2.2. Path length and distribution

Comparisons of travel distance indicated that mice in the Wall condition traveled further than the mice in the No Wall condition, Group: $F(1,10)=12.903$, $P<0.01$; Fig. 7A. Nevertheless, both groups decreased distance traveled over test days, Day: $F(4,40)=17.189$, $P<0.001$. There was no significant difference in the distribution of movements across the table by the two groups. Both groups did, however, reduce the distribution of their movements over days, $F(1,40)=6.395$, $P<0.001$. Stated differently, although the Wall group traveled further than the No Wall group, movements by both groups tended to be mainly along the walls of the test apparatus.

4.2.3. Regional preference

The overall analysis of the time spent in different segments gave a significant effect, $F(15,150)=22.711$, $P<0.001$. Mice in both the Wall and No Wall groups displayed a preference for the table segment containing the visual cue. There was a significant interaction between Group and Segment, $F(15,150)=11.732$, $P<0.001$, Day by Segment, $F(60,600)=12.338$, $P<0.001$, and Day by Segment by Group, $F(60,600)=12.795$, $P<0.001$. A day by day inspection of regional preference indicated that the mice in the No Wall condition displayed an increasing preference for the segments of the table adjacent to the visual cue but there was no similar increase in preference displayed by the mice tested in the Wall condition (see the pattern illustrated in Fig. 8 for stops). After removal of the visual cues, the No Wall group continued to maintain a preference for the previously cued region of the table whereas a similar preference was not observed in the Wall group, Day: $F(4,40)=5.192$, $P<0.01$ and Day by Segment by Group: $F(60,600)=3.576$, $P<0.001$.

Analysis of the time spent in the different segments on the Probe day revealed a significant effect of Segment, $F(15,150)=3.644$, $P<0.0001$ and a significant Group by Segment: $F(15,150)=2.757$, $P<0.0001$, interaction. Individual analyses on the two groups indicated that whereas the mice in the No Wall group continued to show a weak preference for the region of the table where the visual cue had been located, the Wall group did

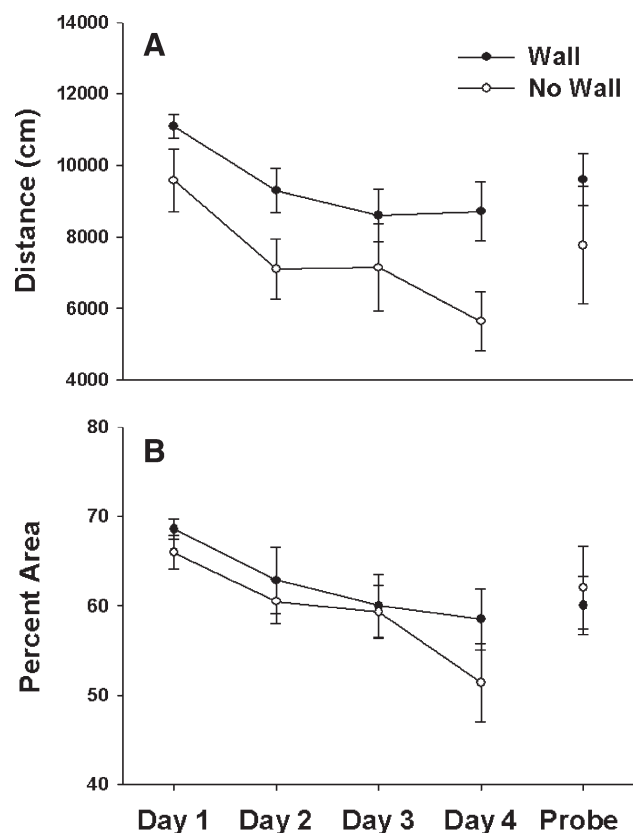


Fig. 7. (A) Distance (mean±S.E.M.) traveled and (B) percent area (mean±S.E.M.) of the table traversed by the No Wall and Wall groups on Day 1 to the Probe day.

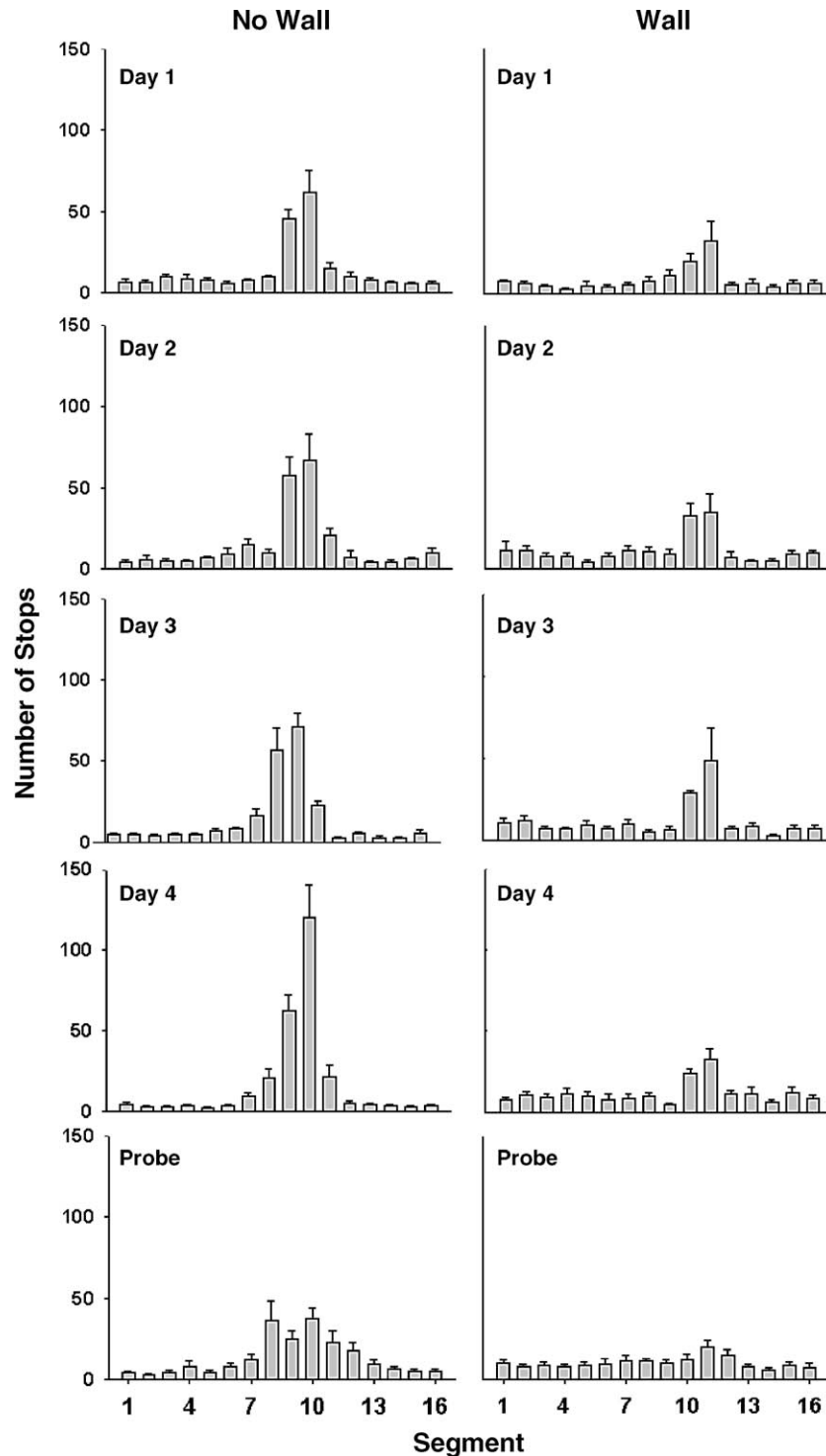


Fig. 8. The number of stops (mean±S.E.M.) as a function of segments (16 pie shaped segments) by No Wall and Wall groups on Day 1 to the Probe day. Note: increased preference for the cue segment of the table in the No Wall condition versus the Wall condition.

not display a similar preference (see Fig. 8 for a similar pattern for the number of stops).

Fig. 8 illustrates that stops made by mice in the No Wall condition occurred most frequently adjacent to the visual cue, Segment: $F(15,150)=31.415$, $P<0.001$, while the preference was similar but less pronounced in the Wall condition, Group: $F(1,10)=13.979$, $P<0.01$. In addition, the number of stops increased adjacent to the cue across test days while, if any-

thing, stops beside the cue decreased in the Wall condition, Group by Segment: $F(15,150)=15.342$, $P<0.001$ and Day by Segment: $F(60,600)=4.136$, $P<0.001$. On the Probe trial, stopping locations were still distributed in the region of the table adjacent to the visual cue for the No Wall group, although the stops were less focused, Day: $F(4,40)=5.192$, $P<0.01$ and Day by Segment by Group: $F(60,600)=3.576$, $P<0.001$.

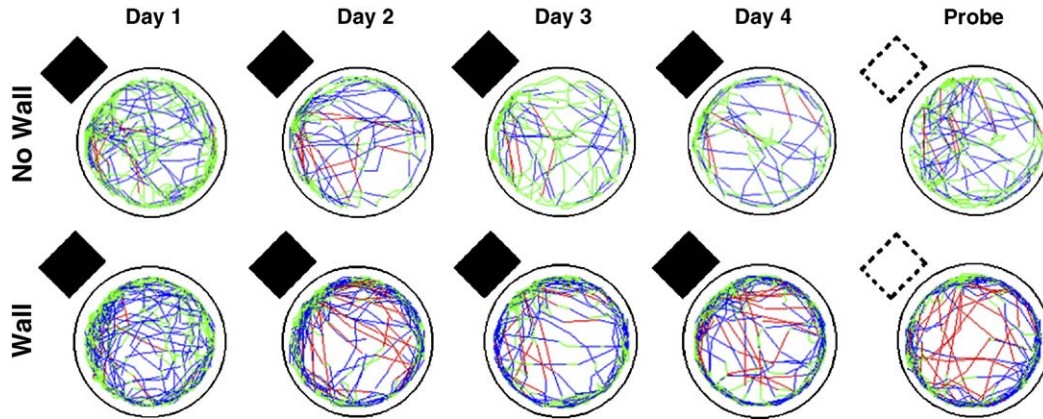


Fig. 9. The speed of progressions between stops from representative mice from the No Wall and Wall groups on Day 1 through the Probe day. Each color designates a speed (Green=1–20 cm/s, Blue=20–40 cm/s, Red=40+ cm/s). The black square equals the visual cue location. Note: movement speeds tend to be faster in the Wall condition. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4.2.4. Speed

Fig. 9 illustrates the speed profiles of representative mice from the No Wall and Wall groups across testing days. Analysis of the proportion of progressions at the three sample speeds gave a significant effect of Group by Speed: $F(2,20)=67$, $P<0.001$. Follow up tests indicated that the mice in the No Wall group displayed more slow speed progressions and fewer high speed progression than the Wall group. There was a trend toward progression speed slowing across test days and then increasing on the Probe trial for both groups, but this difference did not quite reach significance, Day by Speed, $F(8,80)=2.04$, $P=0.052$.

4.3. Experiment 3: exploratory movements in relation to a prominent visual and tactile cue

4.3.1. Spatial distribution of movement

When presented with a visual cue adjacent to one portion of the table and a wall directly across from the visual cue, mice traveled to both cue regions of the table and stopped adjacent to the cues (Fig. 10). Over test days, however, the preference for the region of the table adjacent to the wall increased at the expense of time spent adjacent to the visual cue. On a Probe day, during which the cues were removed, there was an increase in

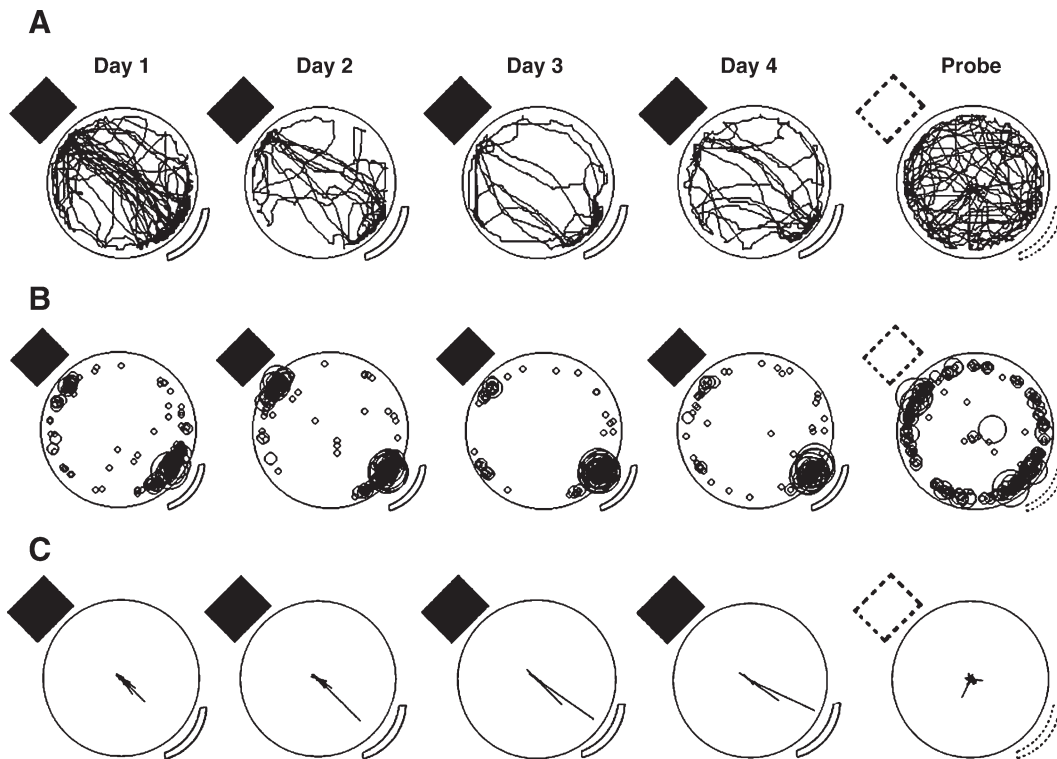


Fig. 10. (A) Paths, (B) stops, and (C) polar histograms from a representative mouse on Day 1 through to the Probe day. Stop duration is represented by the diameter of the circles: 1–2, 3–10, 11–30, and 30+ s. In the polar histograms, the black lines represent the percent time in that segment (16 segments) of the open field. The black square equals the visual cue location. The quarter circle equals the location of the wall. Note: increasing preference for the wall versus the visual cue across test days and the absence of a clear preference on the Probe day.

distance traveled but regional preferences for the previous cue regions were reduced.

4.3.2. Path length and distribution

The analysis of path length indicated that the distance traveled changed as a function of test day, $F(4, 20)=12.939$, $P<0.001$. As is illustrated in Fig. 11A, the mean distance traveled declined on each of the days on which the cues were present. Distance then increased again on the Probe day on which the cues were removed (comparison of Day 4 versus the Probe trial, $t(1, 20)=4.3$, $P<0.05$). The analysis of the distribution of movement indicated that the distribution changes as a function of test day, $F(4, 20)=20.149$, $P<0.001$. As is illustrated in Fig. 11B the mean distribution of travel declined on each day that the cues were present. The distribution of movement then increased on the Probe day when the cues were removed (comparison of Day 4 versus the Probe trial, $t(1, 20)=6.1$, $P<0.05$).

4.3.3. Regional preference

Measures of percent time as a function of table segment indicated that there was a significant effect of Segment, $F(15, 75)=12.031$, $P<0.001$, and there was a significant change in preference across test days, Day by Segment: $F(60, 600)=4.187$, $P<0.001$. The results of percent time mirrored those of

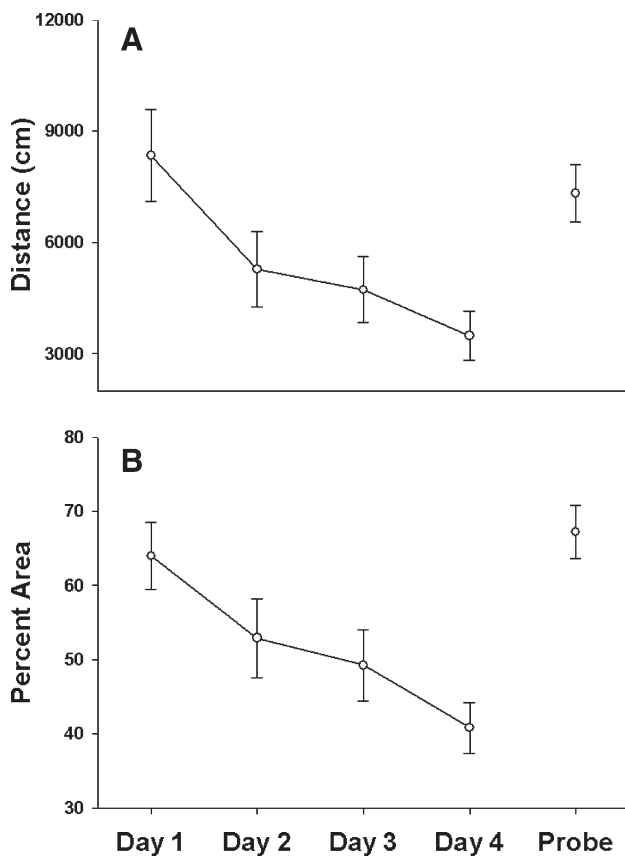


Fig. 11. (A) Distance (mean±S.E.M.) traveled and (B) percent area (mean±S.E.M.) of the table traversed by mice on Day 1 through the Probe day. Note: habituation of locomotion over the test days and dishabituation when the cues are removed on the Probe day.

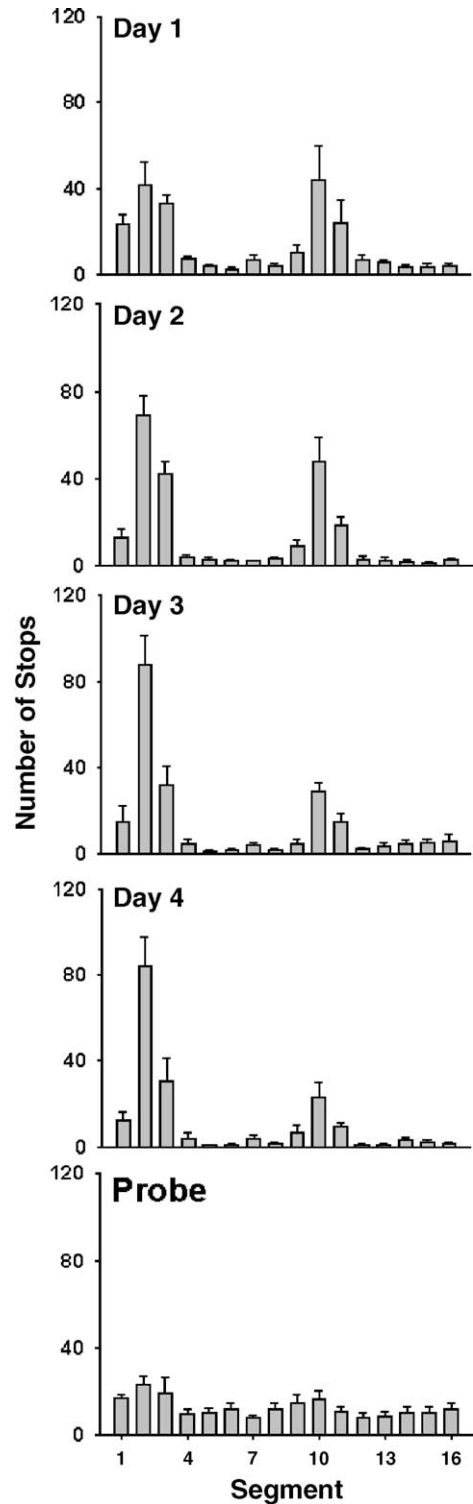


Fig. 12. The number of stops (mean±S.E.M.) as a function of segments (16 pie shaped segments) by mice on Day 1 through the Probe day. Note: increased numbers of stops in segment 2 adjacent to the wall versus decreasing number of stops in segment 10 adjacent to the visual cue.

number of stops (see Fig. 12), as mice preferred the segments of the table next to both cues but showed a strengthening of preference over days for the segments of the table next to the wall. A separate ANOVA on percent time in the different segments on the Probe trial gave no significant difference.

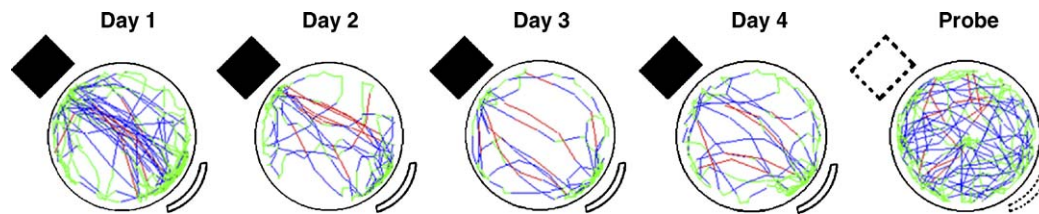


Fig. 13. Speed profiles of progressions between stops for a representative mouse on Day 1 through the Probe test. Each color designates a speed (Green=1–20 cm/s, Blue=20–40 cm/s, Red=40+ cm/s). The black square equals the visual cue location. The quarter circle equals the location of the tactile cue. Note: decrease in speed across test days and increase in speed on the Probe test. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Measures of number of stops as a function of table segment indicated that there was a significant effect of Segment, $F(15, 75)=28.698$, $P<0.001$. As is shown in Fig. 12, the mice made many more stops in the segments adjacent to the visual cue and the wall cue. The distribution of stops across days did change, however, $F(60, 600)=5.358$, $P<0.001$. As is illustrated in Fig. 12, whereas the mice initially stopped equally near the visual cue and wall on the first exposure day, by the fourth exposure day they were stopping more frequently next to the wall. A separate ANOVA on number of stops in the different segments on the Probe trial gave no significant difference.

4.3.4. Speed

Representative speed profiles for one mouse in the open field on Day 1 through to the Probe day are illustrated in Fig. 13. Low speed progressions typically occupied regions of the table near the cue locations. Additionally, mid to high speed movements occurred through the center of the table when the animal moved toward a cue on the opposite side of the table. Speed measures across days gave a significant effect of Day by Speed, $F(8, 80)=9.8$, $P<0.001$. This effect was mainly due to decreases in high speed progressions across the first four exposure days and to an increase in the high speed progressions on the Probe trial. A separate ANOVA on speed comparing Day 4 with the Probe trial gave a significant Group by Speed interaction, $F(8, 80)=3.4$, $P<0.05$.

5. Discussion

The present study investigated the influence of ambient visual and tactile cues on mouse motor (exploratory) activity in an open field. Mice were tested on a circular table around which both visual cues and tactile cues were manipulated. Mice tested in conditions of impoverished cues, either in infrared light or in normal light, displayed little regional preference in their movements. With visual cues present, mice spent disproportionately more time and made more long stops near a visual cue placed near the table or a wall placed adjacent to the table. The mice continued to prefer those locations when the cues were removed. Tactile cues in the form of walls surrounding all or a part of the table suppressed responses to visual cues. The most salient finding of the present study is that mouse locomotor activity is sensitive to cues placed within a testing environment and to cues surrounding the testing environment indicating that testing environment should be considered an experimental variable in studies of locomotor/exploratory behavior.

The present study confirms that in relatively featureless environments the locomotor activity of mice appears to be “unorganized” [7,15]. Locomotor activity was relatively stochastic with respect to distribution on an open table top, in the light or in the dark, and in a walled circular container. At best, in these conditions, locomotor activity was centered near the edge of the test apparatus, but seemingly lacked other spatially organizing features. Nevertheless, even in these conditions, locomotor activity was sensitive to context. Under infrared light, mice covered a greater distance, moved faster, made more stops, and they were more active than in tests under lighted conditions.

The present study also confirms previous work from rats [3,16] that the presence of a salient visual cue can organize locomotor activity and previous work from mice that tactile cues can organize exploratory behavior [7,9,15]. Thus, in the present study, it was found that a partial wall can organize locomotor behavior such that mice develop a preference for a location near a wall. Additionally, the present study shows that with a number of exposures to these cues, the mice maintained preferences for these places when the cues were removed in probe trials. Thus, the mice learned through conditioning to organize their spatial behavior to one or more distally located room cues.

The present study also demonstrates that the organization of locomotor activity is further modified by the presence of more than one salient cue. The presence of a complete wall around the test apparatus suppressed what should have been a response to a salient visual cue. When presented with a partial wall and a salient visual cue, the mice initially preferred a location near the visual cue but shifted their preferred location to the partial wall with repeated testing. Although the wall could also be considered a visual cue, it was not especially salient because it was painted white and the room wall behind it was also white. Thus, given the poor visual acuity of mice [27], it is likely that they took some time to “notice” it. Its lack of distinctiveness as a visual cue may explain why it was not initially preferred by the mice but became preferred once the mice interacted with its tactile property. Nevertheless, in a probe test in which both cues were then removed, the mice visited both cue locations, suggesting that they had learned the location of both cues in relation to other room cues.

It is interesting that some research on spatial navigation in rodents suggest a formative influence of the geometry of the test environment [1,13]. The geometry of the test room was not an experimental variable in the present study, but could be featured

in future work. Nevertheless, it is clear from the present study that non-geometric cues are extremely influential on the behavior of mice. Because the present study did not feature an investigation of navigation ability in the mice, it is unclear whether the mice would use the local cues, which are potent for setting up home bases, for general guidance. It is likely that the objective of home base formation in mice is to find a place that gives a refuge. A strong motivation to find a refuge in a small animal that is subject to extensive predation is likely a behavioral primitive.

In a seminal study, Eilam and Golani [10] introduced the concept of a home base which was operationally defined as a place that rats spend a disproportionate amount of time, and at which they remain immobile or move slowly, groom and rear, and around which they center their excursions. Whereas that study used a featureless environment, the present study shows that locomotor behavior in mice, including distance traveled, movement speeds, and stop durations, are modulated by contextual cues. Additionally the mice established home bases near salient cues. Thus, for mice, it is possible that rather simple rules may explain most of their locomotor activity: (1) find a location that provides a home base, (2) ensure that it is the safest potential home base, and (3) reduce exposure by remaining at the home base.

The main findings of the present study are relevant to debates related to the replicability of test results between laboratories. For example, some studies have demonstrated wide differences in results obtained in seemingly identical testing situations in different laboratories [4,29,30], while other studies find that behavior can be robust across laboratories in that mice are “resistant to environmental manipulations” [7,8,18,19]. The present study does show that both intra-test and extra-test cues can influence behavior as can past experience. Although identical test equipment may be used in different laboratories it will be much more difficult to ensure that the test rooms or other ambient cues are identical. On the one hand, if the test allows animals to respond to cues distal to the test apparatus, behavioral results may be accordingly different. On the other hand, if the test apparatus prevents responding to external cues, behavioral results may be less variable. With respect to the second point, and as shown here, the presence of a wall suppresses not only responses to visual cues but suppresses the development of home base behavior more generally. It is interesting with respect to the latter effect, that when a similar test is given to rats, they display a very strong preference for a location next to a visual cue on a wall (unpublished results).

Although the present study makes the strong point that locomotor behavior can be organized in mice by the introduction of a salient cue, and that this organization can be modified by both visual and tactile cues presented singly or in combination, the study is not exhaustive. Other research has indicated that the shape of the test apparatus may allow the development of specific home bases, e.g., in the corners of a square box, and the introduction of a number of similar objects may produce the development of “selective” home bases near one object [9]. The present study did not examine the influence of many other cues, including auditory, tactile, and olfactory

cues. The influences of other cues may be usefully examined in future work. Nevertheless, the present study did confirm that there is likely a hierarchical relation between salient cues such that certain cues may be preferred or even repress responses to other cues [22].

Although an examination of home base memory was not a central focus of the present study, we did note that the preference for a home base was relatively weak in mice when a salient cue was removed, as contrasted with rather robust conditioning reported in previous work with rats [16]. This finding with mice is generally consistent with other work in a wide variety of testing situations that suggest that spatial memory is comparatively weakly displayed in mice [31–33]. This result is also consistent with a couple of reports showing that it is even difficult to get mice to show a place response by escaping to a refuge [20,25]. Indeed, Pompl et al. [25] went to great lengths to enhance the escape behavior of mice by using a fan and bright lights. Thus, although the test paradigm described here could be used for the study of place memory in mice, it does not offer obvious advantages over other methods of examining place learning.

In conclusion, the present study shows that the motor activity of mice in “exploratory” tests can be organized by a salient visual cue, but that this response can be influenced by a tactile cue. The study also demonstrates that motor behavior is modulated by test context and also suggests that the form of locomotor activity in an activity test may be governed by simple rules related to the formation of a home base by the mice. Insights related to contextual and experiential influences on the organization of locomotor activity of mice may prove useful in examining genetic and neurobiological influences on motor activity [5,15], and may also be relevant to the behavioral differences found in seemingly similar testing situations [4,29,30].

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