



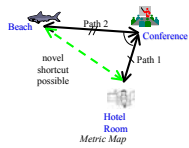
# Human shortcut performance in a structured maze environment



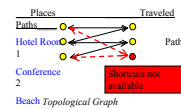
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## What geometric properties of the environment do humans use for navigation?



Does path integration link traveled distances and angles in a metric "cognitive map" that could support novel shortcutting? (i.e. Gallistel, 1990)



Or is route knowledge assembled into a simpler topological graph that preserves only connections, and does not support novel shortcutting? (e.g. Kuipers, et al., 2003)

## Method

Participants: 7 female & 5 male subjects

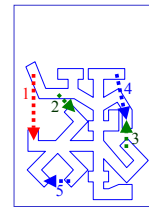
### PROCEDURE

- I. Free Exploration (8 minutes)**  
Subjects instructed to learn the layout of the maze and the objects within
- II. Route Training**  
Subjects walk to object locations in the maze
- III. Shortcut Testing**  
The maze is removed as subjects attempt to walk a direct path between two object locations
- IV. Post-Tests**  
Participants drew a map of the maze and filled out a strategy report.



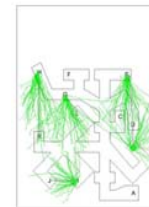
Kaiser HMD (80 deg FOV)  
 Head position/orientation updated at 60 Hz

## Results: Shortcut testing

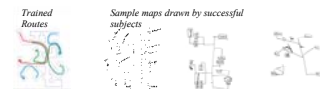


Overall, subjects were unable to complete accurate shortcuts between known object locations

Responses are characterized by an initial estimation of target direction that demonstrates large variability, and increasing error in final position as the trial progresses, suggestive of a lack of corrective actions



## Route training in the maze



Subjects walked between pairs of objects along specific routes (randomly ordered) used in the following shortcut testing.  
 Subjects visited all object locations twice in the maze (22 trials)  
 Subjects that made more than 2 errors were excluded from further testing (2 subjects)  
 10 subjects were able to consistently and accurately (no errors) travel these five routes, demonstrating they possessed a good topological knowledge of the hedge maze

While the extreme shortcuts (1 & 5) followed the correct trend ( $r = .74$ ) for shortcut length ( $p < 0.01$ ), overall subjects were equally inaccurate in final position ( $p < 0.05$ ), missing the target by an average of 215 cm.

Initial and final orientation angles exhibited large variability (AD's = 12 deg), though mean values were within 10 deg (except shortcut 2 = 20 deg undershoot,  $p < 0.05$ )

No differences between any shortcut ( $p > 0.06$ ) for SD's of initial orientation, path length, final orientation, or positions.

	Required Shortcut Distance (cm)	Mean Path Length Walked (cm)	Mean Final Position Error (cm)
Shortcut 1	625	489	203
Shortcut 2	212	409	287
Shortcut 3	212	337	239
Shortcut 4	465	362	188
Shortcut 5	289	242	160

## Shortcut testing without maze

Participants walk from Home to start. The maze/objects are removed, and the subject walks the most direct path to the target location.  
 The subject is returned to Home without walking (via wheelchair).  
 10 subjects walk 5 shortcuts 5 times each



shortcut test: well to turtle



dependent variables

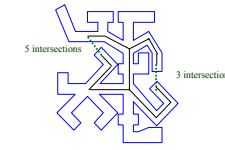
## How might path integration link traveled routes into a metric map?

In contrast to simpler models, the encoding-error model of pathway integration describes how an individual can store the overall metric dimensions of a route instead of just a homing vector (Fujita et al., 1993). This model predicts that errors should increase as metric distance and angles turned increase.

In contrast, it has been shown that perceived distance is systematically overestimated as number of intersections increases (Sadalla & Staplin, 1980).

To investigate this further we compare performance on a pair of shortcuts that have the same metric distances, but differ in number of intersections, and their complementary pair (equal ordinal structure, different metric distances).

## Results: Equal metric distances

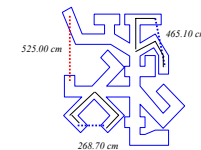


Here we compare performance on two shortcuts that have equal metric route distances (462.40 cm), angles turned (405 deg) and landmarks (212.08 cm) but differ in the number of intersections along the route.

PREDICTION: if ordinal structure systematically affects perceived distance, more accurate shortcut performance should be observed in the route with fewer intersections.

RESULTS: While subjects were significantly more accurate in determining the correct angle to the target in the shortcut with fewer intersections ( $p < 0.05$ ), no significant differences were seen with respect to walked distance or final position ( $p < 0.05$ )

## Results: Equal ordinal structure



Here we compare performance on two shortcuts that both have only one intersection along the route path, but differ in metric distance

PREDICTION: if increased metric distances systematically increase errors, more accurate performance should be observed in the closer shortcut

RESULTS: With the exception of path length, no significant differences were seen across means or SD's ( $p > 0.05$ ) between these two paths

HOWEVER, the shortcut 1 with the longest metric distance of all was significantly worse in all dependent variables, consistent with the pathway integration model ( $p < 0.05$ )

## Discussion and Conclusion

Even though subjects demonstrated excellent topological knowledge of the maze and the objects within, they were really bad at the novel shortcuts when the maze was removed!

Subjects appear to 'ballpark' the target distance/direction and walk without corrections, consistent with studies of path integration.

The comparison of specific route pairs support the the encoding-error model of pathway integration.

This suggests that even when path angles and distances are visually available in training, a topological graph (and not a metric map) appears to be the primary geometry available for human navigation (see also Wang & Spelke, 2002).

It should be noted that even 'simpler' topological knowledge (such as boundary relationships) can be powerful tools for improving way finding (Kuipers et al., 2003).

## References

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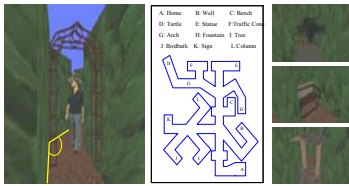
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## Is spatial knowledge more accurate when distances and angles are explicitly available?



12m X 13m Maze

We have demonstrated that humans are unable to perform novel shortcuts in featureless VR environments (Psychonomics, 2002). Here we extend these experiments to a complex VR hedge maze (Harrison et al., VSS 2002).