Do we really need vestibular or proprioceptive cues for homing?

Bernhard E. Riecke, Hendrik−Jan van Veen and Heinrich H. Bülthoff

Max−Planck−Institute for Biological Cybernetics • Tübingen • Germany

E−mail: Bernhard.Riecke@Tuebingen.MPG.de web: www.kyb.tuebingen.mpg.de

MOTIVATION

Do we really need proprioceptive or vestibular cues for homing by path integration?

The literature often suggests that navigation without landmarks (path integration) requires proprioceptive and particularly vestibular cues. Optic flow is often thought to be insufficient, especially for tasks involving observer rotations. To test this notion, we conducted a set of purely visual spatial orientation experiments in a virtual environment providing optic flow information only.

Experiment "BLOBS" and "RANDOM TRIANGLES" were triangle completion experiments: After following two prescribed segments of a triangle, subjects had to return directly to the unmarked starting point. Experiment "TURN&GO" investigated how well subjects can execute simple rotations and translations, which form the basis of more complex navigation tasks. We also conducted two standard mental spatial abilities tests to investigate whether mental spatial ability might be a determining factor for navigation performance.

GENERAL PROCEDURE

We conducted spatial orientation experiments in virtual environments providing no landmarks

Subjects were seated in the center of a large half−cylindrical 180 projection screen and used the mouse buttons to steer smoothly through the simulated scene (see Fig. 1). Experiments were performed in a simulated 3D field of blobs providing a convincing feeling of self−motion (vection) but no landmarks, thus restricting navigation strategies to path integration based on optic flow.

In all experiments, we found a linear correlation between executed and correct values for turns and distances (see Fig's 2, 3 & 4 for examples). The slope of this linear fit ("compression rate") and the signed error are plotted in figures 6−9 to allow for comparisons among the different experiments.

Figure 1
Experimental setup with the half−cylindrical projection screen displaying optic flow from the 3D field of blobs.

EXPERIMENTS

Exp. "BLOBS": Is optic flow information sufficient for homing via triangle completion?

We found a tendency toward mean responses for homing distances but only small systematic errors for turning angles

Procedures:

Each of the 20 subjects performed six repetitions for ten different isosceles triangles (5 angles x 2 turning directions, see Fig. 5).

Results:

The results are summarized in figures 5−9. Averaged over all subjects, the signed errors for turns and distances were negligible. However, homing distances were biased towards mean responses, indicated by the distance compression of 0.58 (see Fig.s 4 & 7). Angular compression did not differ signicantly from its correct value of 1.

Conclusion:

Apart from a regression towards mean homing distances, path integration by optic flow proved sufficient for homing by triangle completion with isosceles triangles.

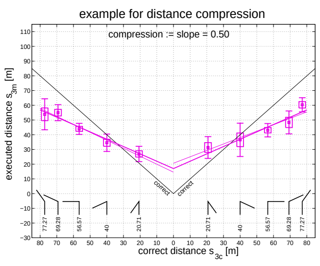


Figure 4: The above graph shows the actual values of the third segment (homing distance traveled) versus the corresponding correct values for one subject. The symmetry of the plot illustrates the similarity of the response for left and right turns. The mean values over the six repetitions are plotted for each of the ten triangle geometries (symbolized by the little icons below). Boxes refer to the standard error of the mean, "whiskers" depict one standard deviation. A linear regression line (in purple) was fitted through the data and captures nicely the main aspects of the data: The slope ("compression rate") of the fit is 0.50, well below the value for perfect performance (slope 1), indicated by the solid black V−shaped lines.

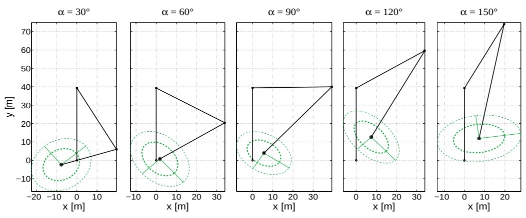


Figure 5: Homing performance in Exp. "BLOBS". The data is pooled over left and right turns, as turning direction had no significant influence on homing performance. Plotted are the mean (centroid), the 95% confidence ellipse (thick dashed line) and the standard ellipse (thin dashed line) for the homing endpoints. The 95% confidence ellipse is a 2D analogue of the confidence interval (mean 2 std err). The standard ellipse is a 2D analogue of the standard interval (mean 1 std dev). It is used to describe the variability of the data and covers roughly 40% of the data (see Batschelet, 1981).

Exp. "TURN&GO": Can untrained subjects perform elementary rotations and translations?

Optic flow information was sufficient for untrained subjects to accurately perform turns and reproduce distances

Procedures:

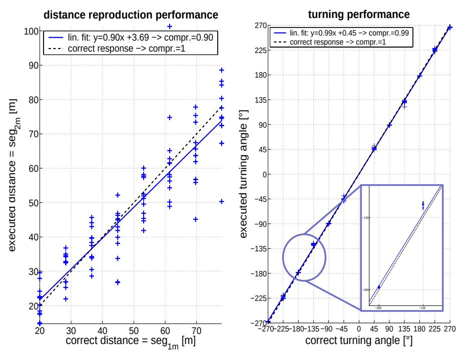
Subjects had to execute turns and reproduce distances using randomized velocities.

Results:

A typical result from one subject is displayed in figures 2 & 3. Of particular note is the small systematic error and within−subject variability especially for rotations.

Conclusion:

Optic flow information alone proved to be sufficient for untrained subjects to perform turns and reproduce distances with negligible systematic errors, irrespective of movement velocity.



Figures 2 & 3: Typical distance reproduction and turn execution response from one subject. The left and right graph show the executed distance respectively turning angle, plotted versus their corresponding correct values. The blue enlargement in the right plot demonstrates the small within−subject variability for turns.

Exp. "RANDOM TRIANGLES": How does homing performance change when each triangle geometry is novel

Homing performance was not worse for randomized triangle geometry

Procedures:

Ten subject who had previously participated in Exp. "BLOBS" completed 60 homing trials each. The lengths of the first and second segments covered a range of 20 to 73m and were independently randomized. The enclosed angle was randomized between 20 and 160 degrees.

Results:

Compared to the isosceles triangles in Exp. "BLOBS", the bias towards mean homing distances (distance compression) was significantly smaller. Moreover, the between−subject variability of compression rates was significantly reduced (see Fig's 7 & 9). Signed errors remained negligible (see Fig's 6 & 8). However, within−subject variability was rather pronounced.

Conclusion:

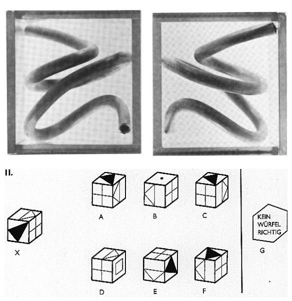
Compared to the simpler isosceles geometry in Exp. "BLOBS", we did not observe the performance decrement expected. This suggest that neither motor learning nor the simplicity of isosceles triangles was a determining factor for homing accuracy.

Exp. 4: Does mental spatial ability correlate with homing performance?

Mental spatial ability scores correlated positively with homing performance

Procedures:

We conducted two standard mental spatial abilities tests (Schlauchfiguren & Würfel Erkennen Test, ISA.6, see pictures to the left) to investigate whether mental spatial ability might be a determining factor for navigation performance.

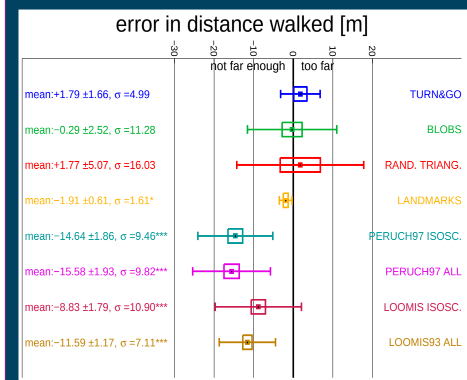


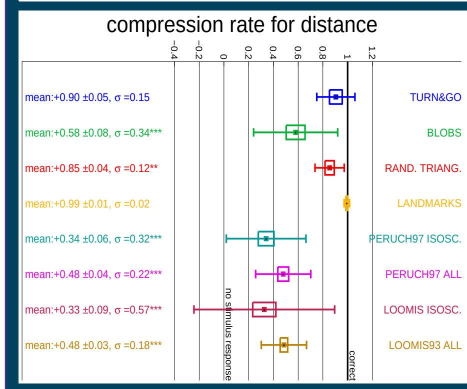
Results:

A correlation analysis revealed a positive correlation between mental spatial ability scores and homing performance in Exp. "BLOBS" and especially in Exp. "RANDOM TRIANGLES". Smaller distance errors correlated with better performance in both spatial ability tests.

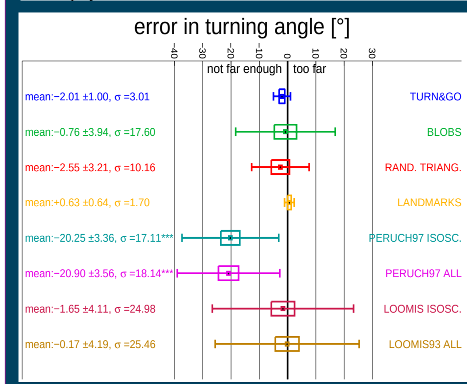
Conclusion:

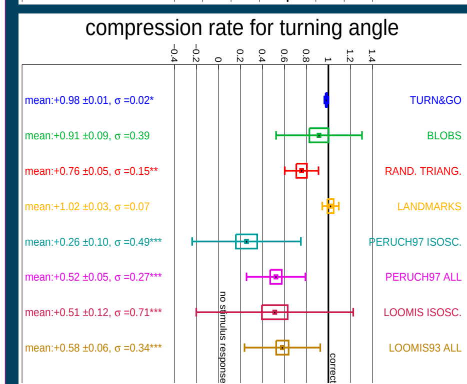
This suggests that mental spatial ability might be a determining factor for homing performance in triangle completion experiments based on path integration.





Figures 6−9
Figures 6−9 show the biases (signed errors) and compression rates (slope of the linear fit) averaged over all subjects for the different conditions: Exp. "TURN&GO", Exp. "BLOBS", Exp. "RANDOM TRIANGLES"; A control experiment with reliable landmarks ("LANDMARKS"); reanalysis of data from Peruch et al. (Perc. 1997) on visual triangle completion within a circle of equal cylinders for isosceles triangles only ("PERUCH97 ISOSC.") and for all triangles ("PERUCH97 ALL"); reanalysis of data from Loomis et al. (JEP 1993) on blind walking triangle completion, again for isosceles triangles ("LOOMIS93 ISOSC.") and for all triangles ("LOOMIS93 ALL"). Boxes and whiskers are centered around the mean and denote one standard error of the mean and one standard deviation respectively. At the left side of each plot, the numeric values of the mean, standard error and standard deviation are displayed.





COMPARISON WITH THE LITERATURE AND CONCLUSION

Optic flow information was sufficient for homing and led to better performance than proprioceptive and vestibular cues from blind walking

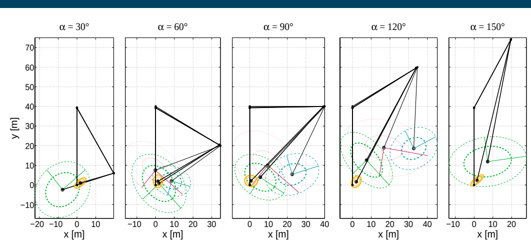


Figure 10: Comparison of homing performances, plotted like in figure 5. Non−overlapping 95% confidence ellipses indicate significant differences between the experiments.

Figure 10 shows a comparison of Exp. "BLOBS" with previous triangle completion experiments by Péruch et al. (Perc. 1997, visual triangle completion in front of a flat projection screen) and by Loomis et al. (JEP 1993, blind walking triangle completion). The results are quantified in figures 6−9.

Distance error and angular compression were substantially more pronounced in the studies by Péruch and Loomis (see Fig.s 7 & 8).

The comparison with data from Loomis et al. suggests that path integration by optic flow, presented via a half−cylindrical projection screen, leads to better homing performance than non−visual homing with proprioceptive and vestibular cues from blind walking. The origin of the performance differences might, however, also be caused by differences in the experimental procedures and awaits further experiments.

The overall level of performance shows that path integration by optic flow alone is sufficient for basic navigation tasks like rotations, translations and homing.

Mental spatial ability test scores correlated positively with homing performance for the more complex triangle completion tasks (Exp. "RANDOM TRIANGLES"), suggesting that mental spatial abilities might be a determining factor for navigation performance.

Compared to similar experiments using virtual environments and a flat projection screen (Péruch et al., Perc. 1997) or blind locomotion (Loomis et al., JEP 1993), we did not find the typically observed distance undershoot and strong regression towards mean turn responses.

Literature

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Péruch, P., May, M. Wartenberg, F. 1997. *Homing in virtual environments: Effects of field of view and path layout*. Perception, 26(3), 301−311.