Supplementary Figure 1

Reaction time as a function of local direction in experiments 1 and 2.

A. Reaction times in Experiment 1 were faster for imagined views facing the back wall of the museums (local North) than for imagined views facing other directions. Repeated-measures ANOVA revealed a main effect of local direction of the imagined heading, $F(3,63) = 8.221$, $p = 0.0001$, and a post-hoc contrast [-3 for the back wall, 1 1 1 for the other directions] confirmed that participants were reliably faster when imagining facing the back wall of the museum compared to the other directions, $F(1, 21) = 23.196$, $p = 0.000008$.

B. Reaction times in Experiment 2 were faster for imagined views facing the back wall of the museums (local North) than for imagined views facing other directions. Repeated-measures ANOVA revealed a main effect of local direction of the imagined heading, $F(3,69) = 11.865$, $p = 0.000002$, and a post-hoc contrast [-3 for the back wall, 1 1 1 for the other directions] confirmed that participants were reliably faster when imagining facing the back wall of the museum compared to the other directions, $F(1,23) = 14.077$, $p = 0.0004$. Error bars in both panels indicate standard error of the mean.
Supplementary Figure 2

Decoding of facing direction and location from fMRI activity patterns in the left superior parietal lobe (SPL).

A. Decoding of local direction in left SPL. *Left panel.* Pattern similarity between views that face the same direction in local space (black bars) was greater than pattern similarity between views that face different local direction (gray bars), (F(1,23) = 27.881, p = 0.00002). There was no main effect of museum, F(1,23) = 1.114, p = 0.302, and local direction did not interact with museum, F(1,23) = 2.359, p = 0.135. *Right panel.* Residual coding of global direction in left SPL. Pattern similarity was greater for views in different museums that faced the same global but different local directions than for views in different museums that faced different directions in both reference frames (t(23) = 2.349, p = 0.028).

B. Decoding of location defined in the local reference frame in SPL. *Left panel.* Average pattern similarity between views in the same or geometrically-equivalent corners (black bars) was greater than average pattern similarity between views in different corners (gray bars) (F(1,23) = 8.429, p = 0.008). There was no main effect of museum, F(1,23) = 1.524, p = 0.230, and local location did not interact with museum, F(1,23) = 1.840, p = 0.188. *Right panel.* Absence of residual coding of location in the global reference frame in left SPL. Pattern similarity in SPL was no greater for views in different museums that were in equivalent locations as defined by the global reference frame than for views that did not share location in either the global or local reference.
frames \( t(23) = 1.191, \, p = 0.245 \). Error bars in both panels indicate standard error of the mean.
Decoding of facing direction from fMRI activity patterns in other functionally and anatomically defined regions of interest.

Decoding of local direction within parahippocampal place area (PPA), occipital place area (OPA/TOS), early visual cortex (EVC), hippocampus, and pre-subiculum. Pattern similarity between views that face the same direction in local space was only marginally greater than pattern similarity between views that face different local directions in the PPA and OPA/TOS (PPA: F(1,23) = 4.247, p = 0.051; OPA/TOS: F(1,23) = 3.463, p = 0.076), while EVC, presubiculum and hippocampus showed no evidence of direction coding (all ps > 0.38). In addition, patterns of activity in OPA/TOS and EVC contained sufficient information to decode the identity of the museum (OPA/TOS: F(1,23) = 5.175, p = 0.033; EVC: F(1,23) = 6.481, p = 0.018), while patterns of activity in PPA, presubiculum, and hippocampus did not (all ps > 0.16). We did not observe interactions between museum and direction coding in any of these regions (all ps > 0.13). In a previous experiment, we observed robust evidence of direction coding within the presubiculum when participants viewed familiar scenes from their college campus. There are at least four differences between the two studies that could potentially explain this discrepancy. First, differences in task: in the previous experiment participants viewed scenes and reported which (canonical) direction they faced in the world, whereas in our current experiment participants viewed words and never explicitly reported their own heading. Second, differences in environmental familiarity: it may be that more extensive training, or training with both idiothetic and allothetic inputs, is necessary for the presubiculum to engage during memory recall. Third, the number of distinct problems that subjects had to solve was smaller in the earlier experiment (16 problems repeated 17 times each) than in the current experiment (96 problems repeated 5 or 6 times); as such, subjects in the earlier experiment may have relied more heavily on episodic memory to re-create the spatial codes retrieved on earlier trials leading to greater presubicular involvement. Finally, the voxel size was larger in the current experiment (3x3x3 mm) compared to the earlier experiment (3x3x2 mm) which might have made presubicular activity patterns more difficult to discern in the current case.
Supplementary Figure 4

Decoding of location from fMRI activity patterns in other functionally and anatomically defined regions of interest.

Decoding of location within parahippocampal place area (PPA), occipital place area (OPA/TOS), early visual cortex (EVC), hippocampus, and pre-subiculum. Pattern similarity between views in the same or geometrically-equivalent corners was not reliably greater than pattern similarity between views in different corners in any of these ROIs (all ps > 0.22). Main effects of museum were observed in OPA/TOS (F(1,23) = 5.151, p = 0.033) and EVC (F(1,23) = 7.311, p = 0.013) but not in PPA, presubiculum, or hippocampus (all ps > .70). We observed no interactions between location and museum in any of these regions (all ps > 0.19). Error bars in both panels indicate standard error of the mean.

Nature Neuroscience: doi:10.1038/nn.3834