Object Position, But Not Identity, Is Decodable During Object Permanence with MEG

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Abstract

When objects are dynamically occluded, we maintain knowledge of their existence—a phenomenon known as object permanence. Despite extensive research on object permanence, the nature of neural object representations under occlusion remains unclear. Specifically, does the neural code maintain perceptual-rich features, or does it shift toward a sparse, conceptual format? Here, we measured dynamic neural representations using MEG in an ecological valid setting. Participants viewed one of five objects (e.g. bike, chair) moving either unobstructed or behind a wall, with the knowledge that the object would either disappear or reappear, while performing a speed-change detection task. Using MVPA decoding, we were able to decode object identity when the object was unoccluded. Throughout occlusion, however, we could decode object positions but not object identity. Notably, when the object was predicted to disappear during occlusion, the neural position signal was traceable only until the moment of vanishing. Our findings suggest that during occlusion, neural signals may reflect simulated spatial information rather than detailed perceptual features, thereby placing important constraints on computational models of object perception in the brain.

Keywords: occlusion; object permanence; MEG; MVPA; vision

Introduction

Object permanence requires that the brain maintain information about objects even when they are not visible. But *what kind* of information is preserved when an object is temporarily occluded? One possibility is that the brain maintains a detailed feature-rich representation, including the object's identity and its spatial location, even when it is occluded. Supporting this view, neural signals in macaque inferior temporal cortex (IT) exhibit "surprisal" responses when an unexpected object reappears after occlusion (Puneeth & Arun, 2016), suggesting that identity-level information is maintained. Alternatively, the neural code may shift under occlusion toward a reduced conceptual format, discarding identity features and retaining only spatial signals (Rajalingham, Sohn, & Jazayeri, 2025). Supporting this view, human neuroimaging studies have shown that identity information cannot be read out during occlusion, while positional information persists (Erlikhman & Caplovitz, 2017; Teichmann, Moerel, Rich & Baker, 2022).

Here, we test these two possibilities directly using an ecologically-valid paradigm (Fig. 1a). Using MEG, we ask whether the brain actively maintains decodable identity and position information of the object during occlusion. We further ask whether the brain drops these representations when the object is expected to vanish during occlusion. In doing so, we aim to determine the nature and format of representations that underlie object permanence in the human brain.

Methods

Participants (N=8) viewed 3.2-second videos in which one of five objects moved horizontally either unobstructed ("no wall") or behind a wall (0.6s occlusion; "wall") and reappeared. Two additional conditions featured the object falling into a hole, either visible ("no wall, hole") or concealed behind the wall ("wall, hole"). Conditions were introduced and presented in blocks, ensuring that participants were familiar with the objects' dynamics (Fig. 1a). Participants maintained central fixation and detected sudden changes in the object velocity (~16% of trials). These task trials were excluded from further analyses.

MEG data was acquired and analyzed using linear support vector machine (SVM) decoding. Object identity was decoded on a per-time-point basis using pairwise classification (chance=50%). For object position decoding in the two wall conditions, the 600-ms occlusion period was divided into three 100-ms bins (50–150, 250–350, and 450–550 ms). SVMs were trained on bin identity using leave-one-object-out cross-validation (chance=33.33%). To probe how predicted disappearance ("wall, hole" condition) affects neural position representation, cross-decoding between the two wall conditions was performed and the confusion matrix diagonal ("hits") was correlated with the bin positions. If position is maintained only until the object falls into the hole, the signal similarity is expected to decay over time.

Results

Do neural signals from MEG carry reliable information about an occluded object's identity and its spatial location? We were able to significantly decode object identity across conditions (Fig. 1b). In the absence of the occluder ("no wall, no hole" condition), decoding accuracy was robust and extended to the periphery. As expected, object decoding was truncated once the object fell into the hole in the "hole, no wall" condition. In the presence of an occluder (wall) we could not decode object identity, regardless of whether participants knew the object would reappear or disappear. In the "wall, no hole" condition, object identity was decodable again after the object emerged from behind the wall. Together these analyses indicate that the identity of an occluded object cannot be decoded from MEG signals.

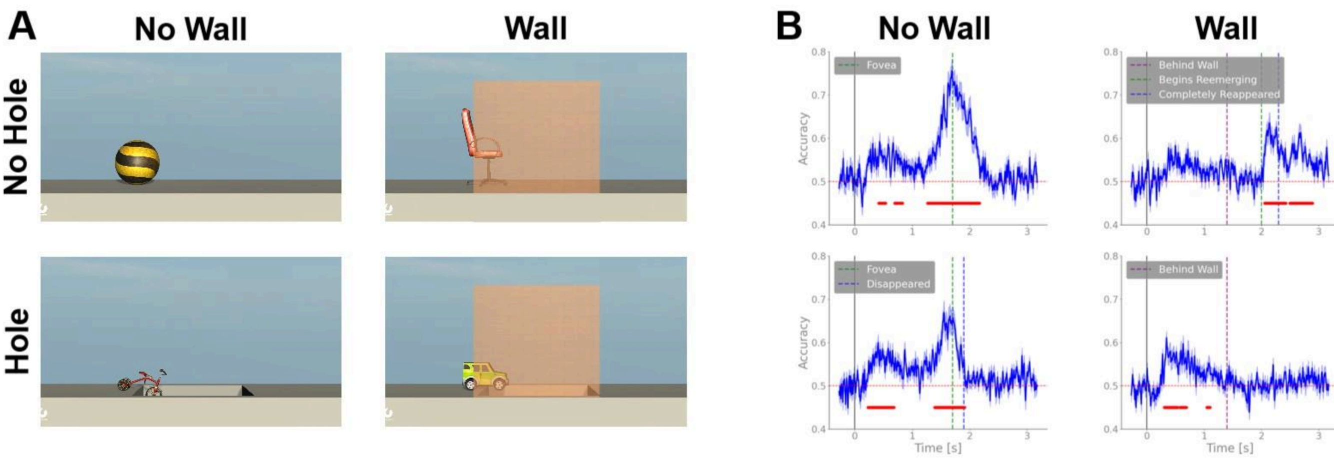

Figure 1: **A**. Stimuli. Walls were opaque during the presentation. **B**. Object identity decoding accuracy. Red horizontal lines: significant clusters. Red dotted lines: chance level.

We then evaluated whether the object's position was represented. In the "wall, no hole" condition, object position was significantly decoded (acc=42.89%; p=0.004, chance=33%), whereas in the "wall, hole" condition, decoding did not reach significance (acc=41.93%; p=0.156). Although overall accuracies did not differ significantly (p=0.371), cross-decoding between wall conditions revealed further insights. While similarity in the confusion matrices was high in the first occlusion bin (Fig. 2A), it decreased over time (r=-0.472, p=0.020; Fig. 2B). This pattern suggests that the object's position is maintained during occlusion, but only tracked until the predicted moment of vanishing (i.e., when the object falls into a hole). In the "wall, hole" condition, since the object cannot reappear, position is tracked even though it is not relevant for the speed-change detection task.

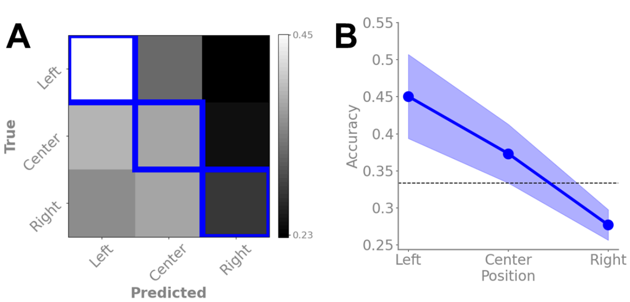

Figure 2: **A**. Confusion matrix from cross-decoding object position. **B.** Decoding accuracy for object position from left to right. Shaded areas: SEM.

Discussion

In this study, we employed videos of naturalistic stimuli and introduced conditions in which an object either reappears or completely disappears from the scene. We were unable to decode object identity during occlusion (see also, Erlikhman & Caplovitz, 2017; Teichmann et al., 2022). However, we successfully decoded object position, either continuously maintained throughout occlusion or only up to the predicted vanishing event. The latter finding supports recent work suggesting that primates engage in mental simulation of the external world during occlusion (Rajalinham et al., 2025).

Why would object position be maintained even when it is not task-relevant? One possibility is that, irrespective of task demands, object position is continuously updated to prevent surprise upon reappearance, while perceptual identity features, being commonly stable, are not actively updated (Teichmann et al., 2022). This idea is in line with the observation that, when an object changes identity during occlusion but reappears in a spatiotemporally consistent manner with its entry, it is perceived as a single, continuous entity (Flombaum, Kundey, Santos & Scholl, 2004). Alternatively, it is possible that object identity is maintained in an activity-silent state that evades detection by MEG (Stokes, Muhle-Karbe & Myers, 2020), which would be consistent with findings of IT neurons responding to unexpected identity changes during occlusion, even in absence of any task (Puneeth & Arun, 2016).

Taken together, our findings suggest that during object permanence, neural signals predominantly represent simulated spatial information rather than detailed perceptual features. This result implies that the brain maintains an active internal model of the world that supports information about an object's continuity even in the absence of visual evidence. Our findings motivate future work into how task demands and neural coding schemas shape the availability of object information when objects are no longer visible.

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