Neural Dissociations between Perspective Transformation and Mentalizing

Eda Bayram

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Visual perspective taking (VPT), described as the anticipation of visual experiences of others, and mentalizing[1], anticipating mental states of others, are close concepts as they both require the ability to construct representations departed from one's own. Specifically, a potential causal relationship between mentalizing and level-2 VPT, the ability to transform perspective to another vantage point in space, intrigued researchers in social cognitive neuroscience due to considerable phylogenetic and ontogenetic links between them (Kessler & Rutherford, 2010). Theoretically, both rely on the recognition of perspective differences, acknowledging that others may hold a different knowledge of the world. Consequently, overlap in their neural correlates could illuminate the brain mechanisms involved in processing these perspective differences. This essay critically examines three seminal neuroimaging studies—Aichhorn et al. (2006), David et al. (2008), and the meta-analysis by Schurz et al. (2013)—to explore the associations and dissociations between level-2 VPT and mentalizing.

Visual perspective taking (VPT) is typically categorized into two levels: level 1 (VPT-1) and level 2 (VPT-2) (Flavell et al., 1981). VPT-1 involves determining what another person can see, whereas VPT-2 requires understanding how a scene appears from another person's point of view. Inherently, these levels rely on distinct cognitive processes. VPT-1 involves

[1]In this essay, the term 'mentalizing' is adopted to refer to the ability to attribute mental states to others, such as beliefs, desire, intentions and emotions, instead of the term 'theory of mind (ToM)'. This terminology is aligned with David et al. (2008), one of the focus papers of the essay and also with the recent commentary on mentalizing by Quesque et al. (2024), where ToM is distinguished as set of principles or heuristics used while inferring about mental state of others.

tracking another's line of sight to evaluate the visibility of an object, while VPT-2 necessitates a spatial transformation of the scene relative to another vantage point, distinct from one's own perspective. Consequently, VPT-1 is often referred to as *perspective tracking*, whereas VPT-2 is termed *perspective transformation* or *viewer/self-rotation*. Additionally, VPT-1 is linked to projective spatial prepositions such as "in front" and "behind", assessing whether an object is visible or occluded from another's line of sight (Kessler & Rutherford, 2010). In contrast, VPT-2 involves understanding spatial relationships like left/right from another's perspective.

VPT-2, rather than VPT-1, is considered more closely aligned with or even a precursor to mentalizing (Kessler & Thomson, 2010) for several reasons. First, representing perspective differences is strictly required both in mentalizing and VPT-2 tasks, while its necessity is arguable for VPT-1 (Perner et al., 2003). Perspective difference in visual context is defined as seeing the same object differently. In VPT-1 tasks, one does not necessarily have to understand that the same object can be seen differently by the other just to assess whether it is visible to the other (Moll & Tomasello, 2006). Yet for perspective transformation in VPT-2, this understanding is prerequisite. Second, non-human primates, while capable of VPT-1, struggle with VPT-2 tasks, paralleling their difficulties with basic mentalizing tasks (Tomasello et al., 2005). This suggests a potential evolutionary pathway where VPT may scaffold more complex inferential abilities, such as mentalizing. Third, developmental evidence reinforces this connection. VPT-2 typically emerges around age four, later than VPT-1, coinciding with the developmental milestone of understanding false beliefs (Wimmer & Perner, 1983). This is often viewed as overcoming egocentric biases, similar to understanding perspective difference, an ability required for both VPT-2 and mentalizing. Finally, children with autism spectrum disorder (ASD), who typically face challenges with mentalizing tasks, as well as struggling with VPT-2 (Hamilton et al., 2009), further highlighting the link between these processes.

Despite the evidence supporting a close relationship between VPT-2 and mentalizing, functional distinctions remain. Unlike mentalizing, VPT-2 does not involve ascribing mental states such as emotions, desires, or preferences to others. Nonetheless, prior neuroscience literature has identified the temporoparietal junction (TPJ) as a critical brain region implicated in both VPT and mentalizing. A closer examination of the aforementioned neuroimaging studies sheds light on the specific overlaps and dissociations in their neural substrates.

The first study, conducted by Aichhorn et al. (2006), investigates the brain regions associated with representing perspective differences, a key requirement for both VPT-2 and false belief tasks. The false belief problem, a type of mentalizing task, involves inferring another's mistaken belief about the world. Previous research identified three brain regions commonly implicated in false belief reasoning: the posterior superior temporal sulcus (pSTS), the paracingulate region of the medial prefrontal cortex (mPFC), and the temporal poles.

To explore these regions, Aichhorn et al. (2006) employed a 2x2 factorial experimental design that combined perspective-dependent and perspective-independent factors with first-person (self) and third-person (avatar) perspectives. The experiment included six conditions (a–f): (a) and (b) required judgments of spatial relations in the scene from the avatar's and self's perspectives, respectively; (c) and (d) involved perspective-independent judgments of object properties, again from the self and avatar perspectives; (e) involved verifying a camera's perspective of the scene, while its control condition (f) required judgments about the presence of multiple object types in the scene. The conditions are depicted in Fig. 1. As seen, (a-d) are designed as sentence verification tasks, requiring participants to respond by true or false. Among all the conditions, only (a) and (e) actually required perspective-dependent visual transformations. Crucially, condition (a) necessitated adopting the avatar's perspective in a VPT-2 sense, while condition (e) required adopting the perspective of an inanimate camera. Accordingly, the authors hypothesized that the brain regions involved in false belief reasoning would be activated during condition (a), reflecting the processing of perspective differences.

Their findings revealed no significant differences in response times across conditions. In their ROI analysis, the authors grouped conditions (b) and (c) with the perspective-relevant conditions, arguing that the task and instructions in (b) and (c) may have evoked perspective-related thoughts. Only then, comparing conditions (a, b, c, e) against (d,f) revealed significant activation in the pSTS/TPJ but not in the mPFC. However, ambiguity in the experimental design may have obscured the clarity of their findings. First, the use of different types of stimuli across conditions may explain the absence of significant response time differences. Second, the sentences used in perspective-dependent conditions (a) and (b) were limited to "in front of" and "behind of" statements which are associated with VPT-1 processes, rather than "left of" or "right of," which require the spatial transformations characteristic of VPT-2. As the problem in (a) can be solved via VPT-1 processing, VPT-2 may have been avoided due to its greater cognitive demands (Kessler, 2000; Michelon & Zacks, 2006).

Despite these limitations, Aichhorn et al. (2006) concluded that the pSTS/TPJ is associated with processing perspective differences in both false belief and VPT-2 tasks. They categorized these as "cold cognition" tasks, which involve no emotional attribution. In contrast, they linked the mPFC to mentalizing tasks requiring emotional attribution, or "hot cognition." This distinction aligns with the framework proposed in recent commentary by Quesque et al. (2024), which differentiates mentalizing about affective states from mentalizing about beliefs. Moreover, Aichhorn et al. (2006) noted that the ventral pSTS is associated with emotional attribution, while the dorsal pSTS is linked to processing perspective differences. Their findings highlight the proximity of belief reasoning and VPT-2 in terms of perspective processing, distinguishing them from affective mentalizing tasks.

The second study, conducted by David et al. (2008), investigates the extent to which VPT-2 and mentalizing share neural substrates. Unlike Aichhorn et al. (2006), their experiment included a mentalizing condition requiring preference attribution in addition to a VPT-2 condition. Their 2x2 factorial design used identical stimuli across conditions, varying only the task instructions. As depicted in Fig. 2, each stimulus depicted an avatar expressing a preference for one of two objects in front of him, with one object slightly elevated. In the third-person perspective condition, posing VPT-2 problem, participants determined which object was elevated with respect to the avatar standing face-to-face with the participant. In the third-person mentalizing condition, participants inferred the avatar's preference based on bodily gestures. First-person perspective and preference judgment conditions served as controls.

David et al. (2008) found that response times were shortest in the first-person perspective condition and that participants were more accurate in perspective-taking tasks compared to mentalizing tasks. These results suggest that mentalizing imposes greater cognitive demands than VPT-2. Neuroimaging data revealed significant activation in the right pSTS during the third-person mentalizing condition compared to the VPT-2 condition. However, no significant activation was observed in the mPFC or TPJ during either task. Further analysis of regions in the right posterior temporal cortex implicated in prior studies found activation only during the third-person mentalizing condition. They concluded that mentalizing is dissociated from

VPT-2 in the right posterior temporal cortex, especially at the right pSTS, which is responsible for inference of others' preferences, not required for VPT-2.

David et al. (2008) made a valuable contribution by comparing affective mentalizing to VPT-2 using identical stimuli, allowing for direct comparison of response times. However, their VPT-2 condition, designed to elicit 180-degree viewer rotation, could potentially be solved by transposing left and right without requiring perspective transformation. Although they argue against this possibility based on response time data, the lack of explicit timing for transposition operations leaves room for doubt. Future studies could address this by testing viewer rotations at angles other than 180 degrees.

The third study, a meta-analysis by Schurz et al. (2013), examines brain regions commonly activated in false belief and VPT-2 tasks. The analysis included five VPT-2 studies, three of which reported activation in the dorsal left TPJ, but not the right TPJ, overlapping with regions activated during false belief reasoning. Schurz et al. (2013) concluded that the dorsal left TPJ supports the representation of perspective differences required for both VPT-2 and false belief tasks, while the right TPJ is more closely associated with belief and desire reasoning.

They also offered an explanation for the findings of David et al. (2008), who reported ventral right pSTS activation yet no TPJ activation during mentalizing tasks. According to Schurz et al. (2013), this reflects the demands of preference attribution of their mentalizing task rather than perspective processing. However, David et al. (2008) did not report TPJ activation for VPT-2 either, likely because their analysis focused on regions in the right temporal cortex, while VPT-2 is more strongly associated with the left TPJ.

Although Schurz et al. (2013) provided valuable insights, the limited number of VPT-2 studies included in their analysis makes it challenging to establish consistent patterns. An updated meta-analysis incorporating recent VPT-2 neuroimaging studies would help clarify these findings.

In evaluating the contributions of these three studies, clear neural dissociations emerge between VPT-2, mentalizing about beliefs, and mentalizing about affective states. The findings suggest that VPT-2 predominantly engages parietal and premotor regions rather than temporal areas, indicating its reliance on embodied and motor processes rather than on the cognitive mechanisms associated with mentalizing. This sensorimotor embodiment of VPT-2 has been further explored in subsequent work by Kessler and Thomson (2010) and Kessler and Rutherford (2010).

False belief tasks, on the other hand, appear to preferentially engage the left TPJ, in contrast to mentalizing about affective states. This could be potentially because they require the processing of perspective differences akin to VPT-2, rather than the broader social reasoning involved in mentalizing about affective states. Mentalizing about affective states, however, activates more ventral regions in the right temporal cortex rather than dorsal regions, reflecting its focus on interpreting social and emotional cues rather than spatial transformations.

These neural dissociations underscore the importance of distinguishing between different types of perspective-taking and mentalizing in both research and theory. While VPT-2 and false belief tasks share a reliance on perspective differences, their distinct neural substrates reflect their varying cognitive and embodied demands. Similarly, the divergence between belief-based and affective mentalizing emphasizes the multifaceted nature of social cognition and its distributed processing across different brain regions.

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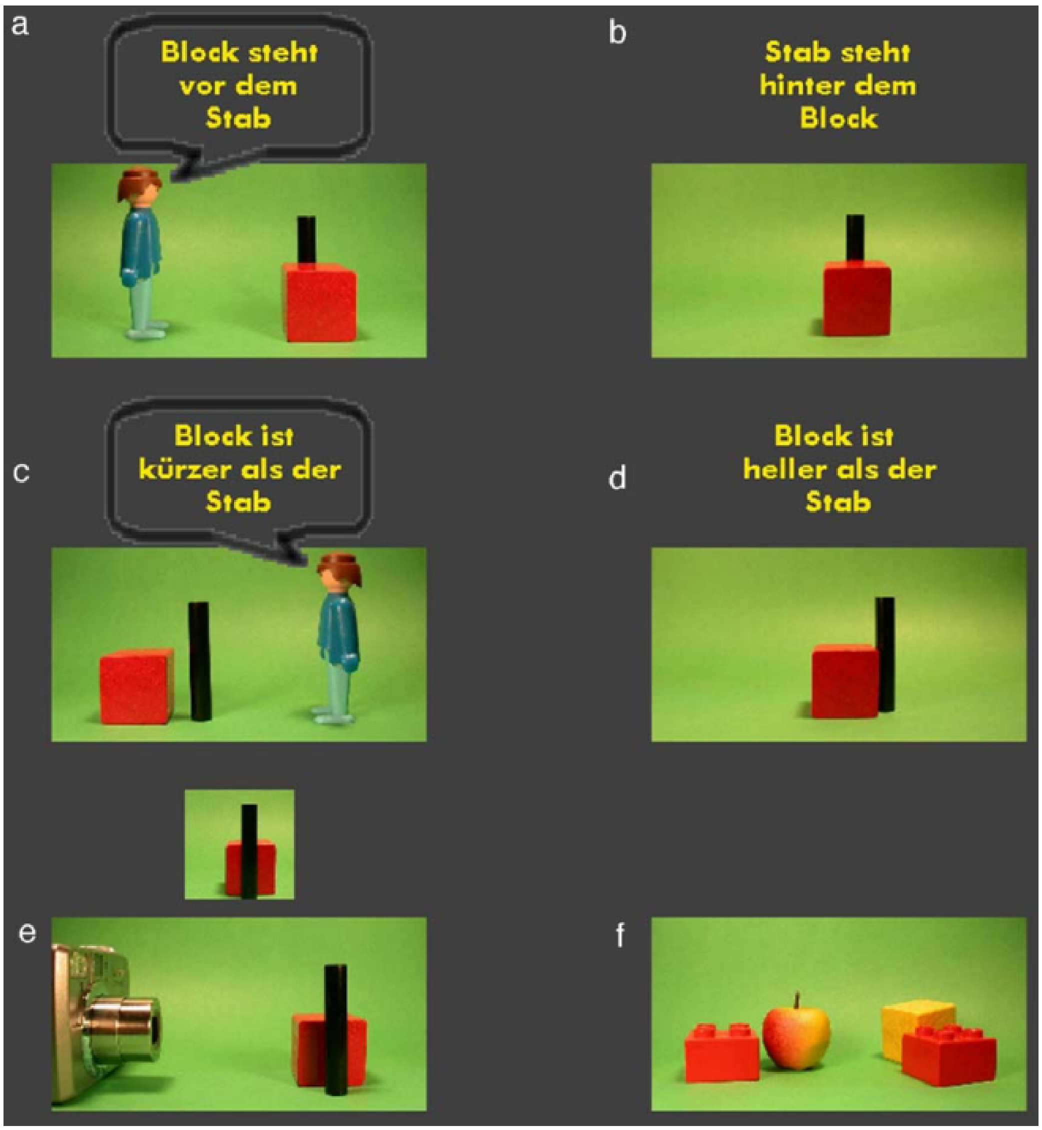

Figure 1: Experiment design of Aichhorn et al. (2006), figure is taken from their paper.

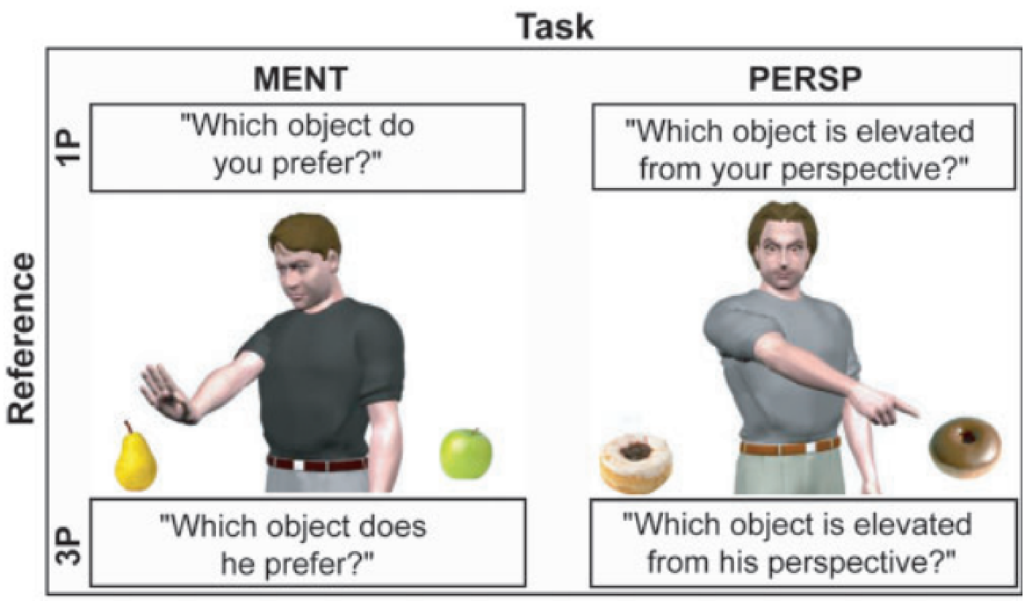

Figure 2: Experiment design of David et al. (2008), figure is taken from their paper.