EEG theta rhythm predicts and prepares for itinerary replanning before target onset during an active spatial navigation task

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Introduction

Active spatial navigation is a complex skill, requiring the integration of spatial memory, internal self-motion cues (vestibular, proprioceptive), external sensory information (visual, tactile), and motor functions[1].

The "Virtual House Locomotor Maze" (VHLM)[2] is a novel paradigm based on the "Virtual Carpet" technology[3], assessing inhibitory control, cognitive flexibility, place and direction errors, as well as navigation strategy kinematics, during active navigation in a realistic behavioral situation[4,5].

In the current study, we used the VHLM, surface electroencephalography (EEG) and inverse modelling (swLORETA)[6,7] to investigate **the brain dynamics and signal sources characterizing cognitive flexibility during itinerary inhibition and replanning.**

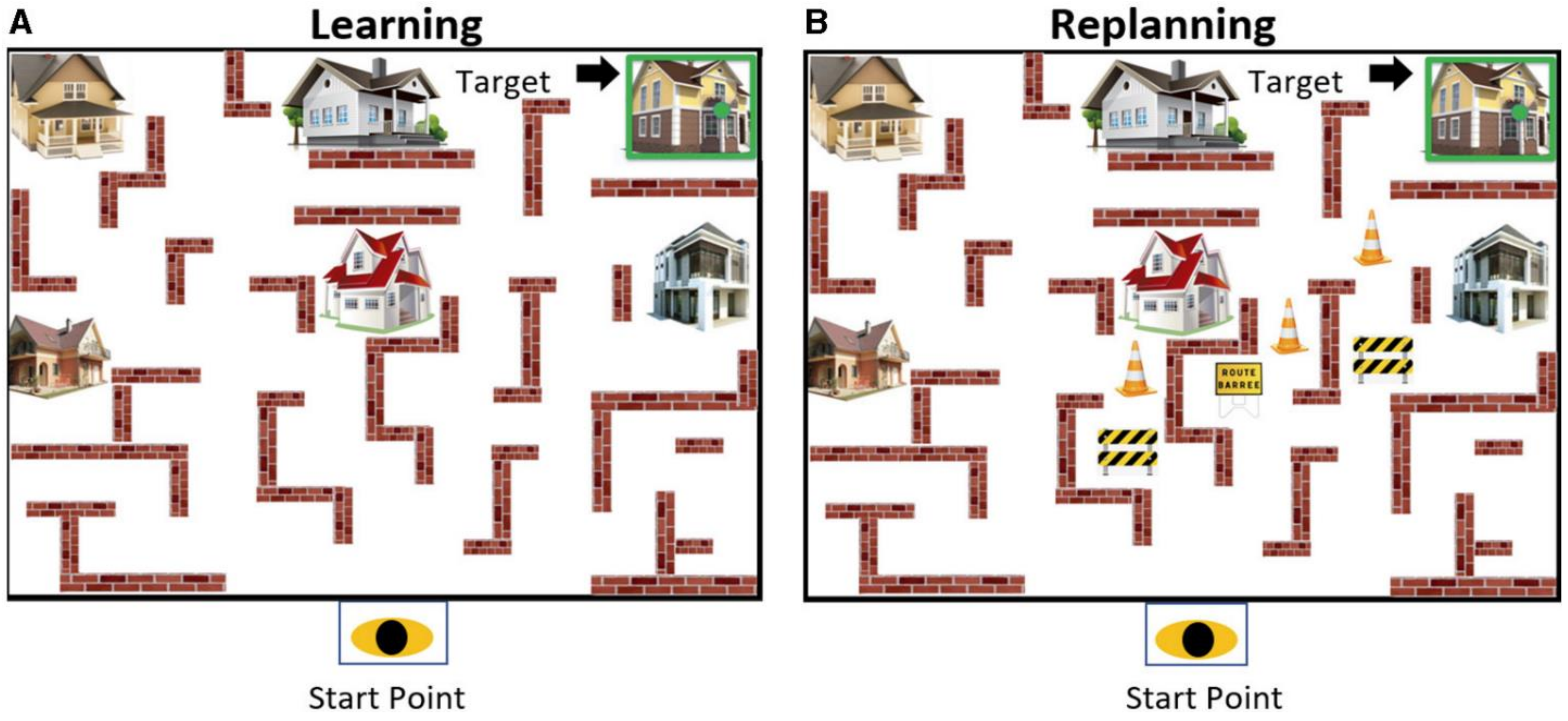

Figure 1. The Virtual House Locomotor Maze layout (adapted from Castilla et al. 2021).

Methods

A virtual city with 6 houses was projected on the floor. Participants navigated to the same target house 5 times along the same route (**Figure 1**, panel A, learning). On the 6th attempt, the overlearned path was obstructed, requiring participants to find a new route to the target (**Figure 1**, panel B, inhibition of overlearned route and replanning).

EEG activity of 19 participants was analyzed, comparing brain activity during the learned condition (NAV5) and the inhibition and replanning condition (NAV6).

Target onset (t0) occurs when the target house is visually cued by a green square. Epochs include a 2 sec baseline, followed by a 4 sec period after t0.

Results

Figure 2 : A grand average topographical analysis of the event-related spectral perturbation (ERSP) in the theta rhythm (3-5 Hz) revealed significant differences between NAV5 and NAV6 from -1350 ms to 1800 ms relative to t0. **Here we focus on the time interval before t0.** From -1250 ms to -1050 ms, NAV6 elicits an increase in theta power, compared to NAV5, most significantly at bilateral frontal-central and right parietal-occipital locations.

Figure 3 : swLORETA source localization analysis revealed that in the -1150 ms to -1050 ms interval, the left cingulate cortex (BA24) contributes significantly more to the replanning task (NAV6), compared to the learned navigation task (NAV5). Additionally, the right primary motor cortex (BA4), right anterior cingulate cortex (BA24) and left sensory associative cortex (BA5) contribute more to the inhibition and replanning condition, compared to the learned path condition.

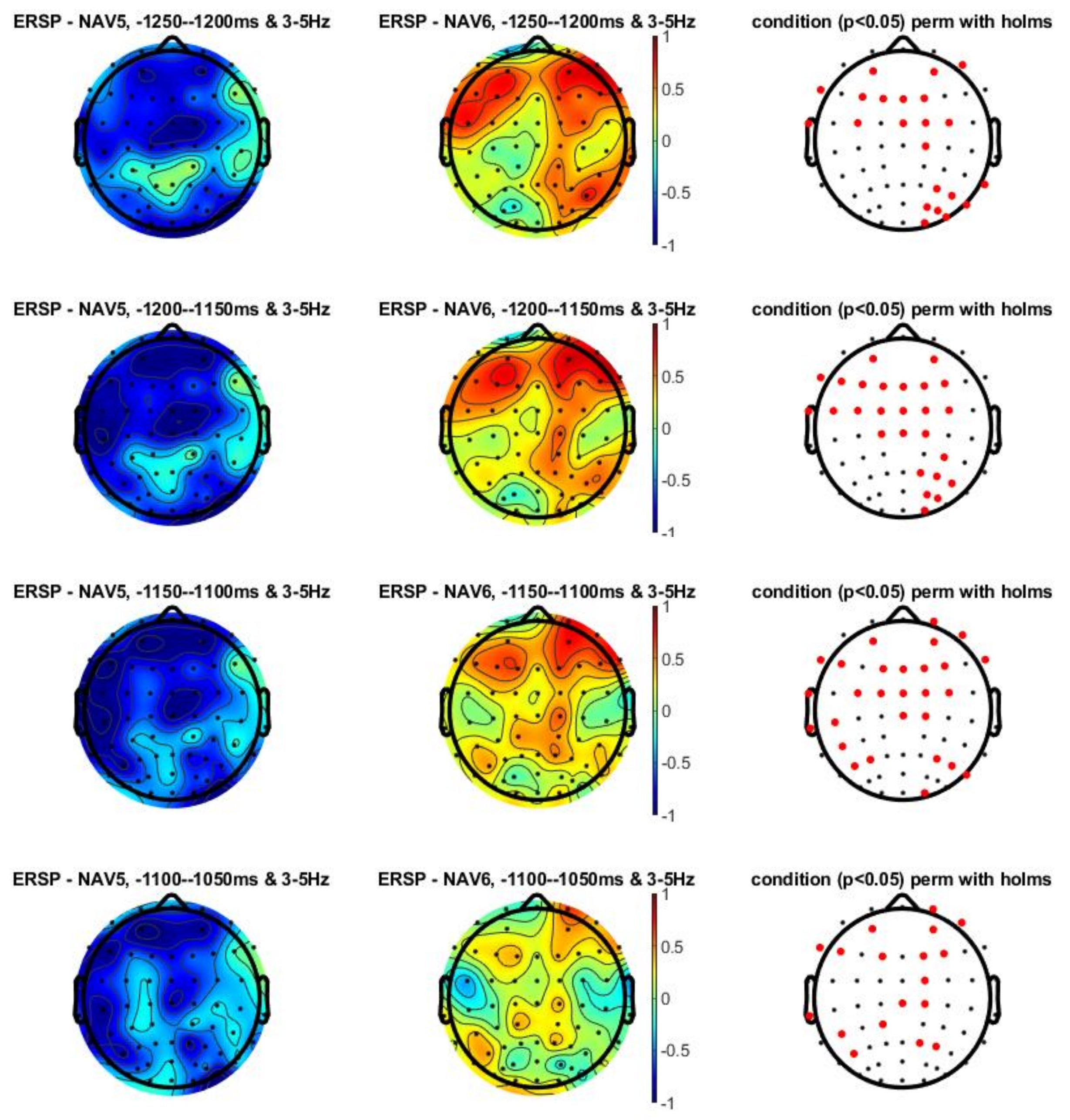

Figure 2. Topographical ERSP analysis of the theta rhythm (3-5 Hz) during the NAV5 (left) and NAV6 (center) conditions in the -1250 ms to -1050 ms interval, with permutation statistics corrected for multiple comparisons (right, p<0.05). Red = increase, blue = decrease in theta power. In the statistics panel, electrodes presenting statistically significant differences are shown in red.

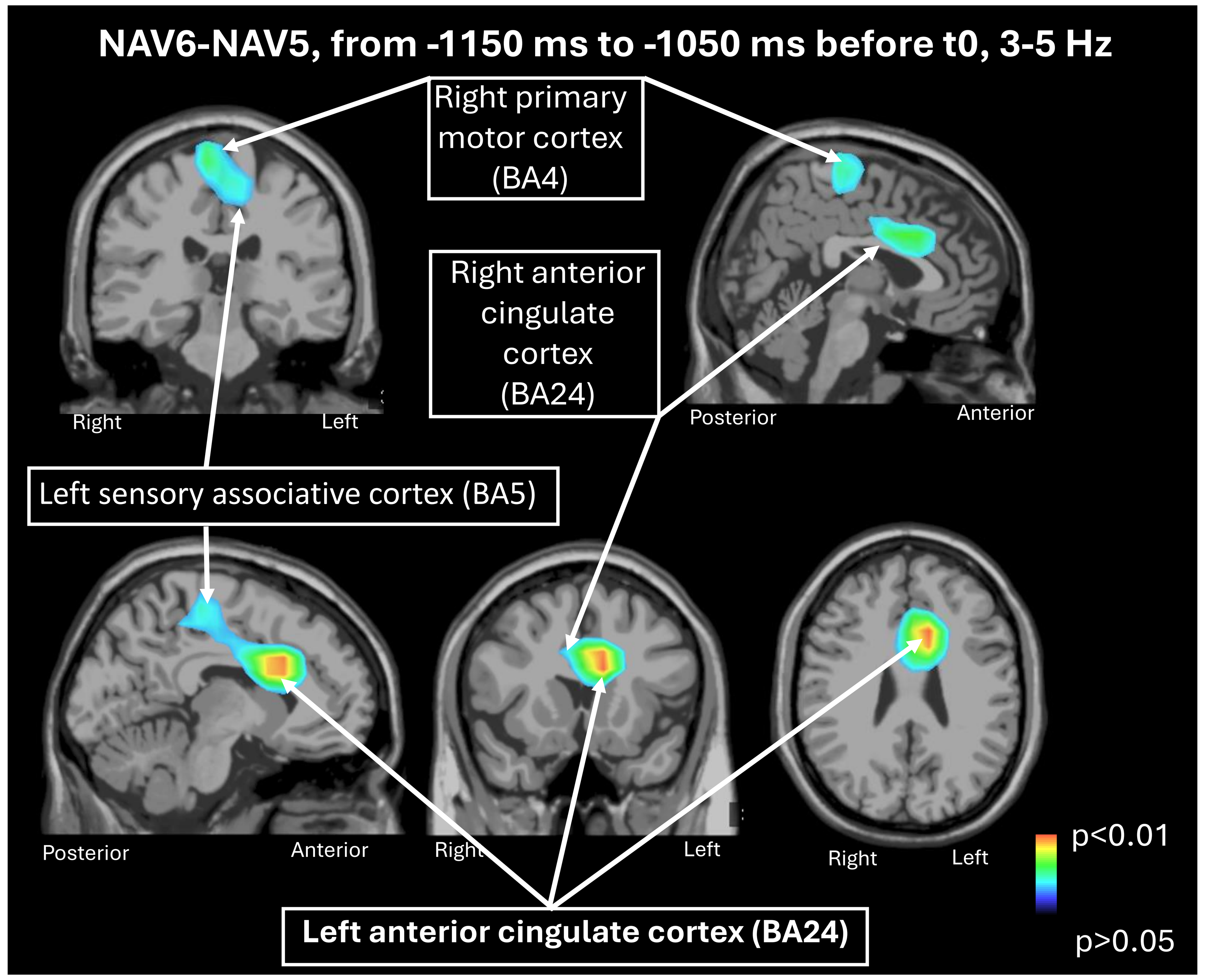

Figure 3. swLORETA source localization of the theta rhythm (3-5 Hz) generators during the time interval from -1150 ms to -1050 ms before target onset, contrasting NAV6 – NAV5 conditions.

Conclusions

Our results suggest that the brain:

1) **anticipates obstructed trials pre-target onset;**
2) **shows reduced theta during well-known itineraries (NAV5);**
3) **resumes theta synchronization when predicting obstruction and replanning (NAV6).**

BA24 has been linked to error awareness, monitoring and dynamic regulation of performance[8,9]. BA5 participates in the decision to withhold or execute movement[10] and in visuomotor attention[11], while BA4 participates in motor cognition and control[12].

Our results suggest that theta activity in these regions allows to track and predict the deviant events, as well as to prepare motor behavior accordingly, once a routine is installed.
In addition to revealing the normal brain activity, the VHLM may be useful for detecting executive function, inhibition and visuo-spatial deficits in patients or during rehabilitation.

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