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Talk Title: Adaptation to the sensorimotor delay occurs in the movement frequency space, not in the domain of time

Abstract:

The brain receives sensory feedback of an action with a necessary delay, due to conduction and processing delays. How the brain adapts to such delays has been extensively studied, typically using the metric of ‘time’. However, our daily motor activities are continuous and involve multiple movement frequencies, meaning these delays can vary with the pattern of the ongoing action. Here, we demonstrate that the brain encodes sensorimotor delay as a parameter in the frequency space, not in the space of time, possibly to robustly adapt to varying delays across different movement frequencies.

In our study, participants were asked to keep the position of a cursor on a sinusoidal path continuously streamed on the screen. Participants held a static handle with their right-hand, and the left-right cursor position on the screen was controlled by applying force on the handle, to the left or to the right. In Experiment 1, participants learned to track the path requiring 1Hz left-right movements under a 250ms visual cursor delay. After learning to predictively move the cursor 250ms ahead of the current path position, they performed the same task at different movement frequencies (0.5, 0.75, 1, 1.25Hz) under an error-clamp condition where the visual cursor always tracked the target path (no apparent visual error information). This was done to eliminate the effect of online feedback to evaluate the feedforward component (i.e. the adapted model) of action. Participants overcompensated for slower (low frequency) movements and delayed for faster (high frequency) ones, indicating a lack of generalization of delay adaptation across different movement frequencies. However, converting the 250ms delay into a phase delay of the movement (90 degrees in the 1Hz condition) exhibited a generalization function centered around 1Hz, suggesting that sensorimotor delays are coded based on movement phase.

Experiment 2 further investigated this hypothesis using an interference paradigm.

Participants were initially trained to track a 1Hz movement path with a cursor-delay of 250ms. They then performed the task at both 1Hz and 0.5Hz movement frequencies. In the time-consistent condition, the delay was maintained at 250ms across frequencies, while in the phase-consistent condition, the delay for the 0.5Hz movement was set to 500ms (equivalent to a 90-degree phase delay in both 1Hz and 0.5Hz movements). If the sensorimotor delay is encoded in the time domain, the tracking performance of 1Hz path should be disturbed by the additional 0.5Hz movement only in the phase-consistent condition. This is because the time of the delay differs between the two frequencies. However, if the delay is encoded as the phase-delay of the movement frequency, time-consistent condition having different phase delays across different movement frequencies should be disturbed, even having same delay time. Supporting the phase-delay adaptation hypothesis, disturbance in delay adaptation was observed only in the time-consistent group. This pattern was also confirmed across various frequency pairs (1Hz vs 0.75Hz, 1Hz vs 1.25Hz) and in situations where the movement frequency varied continuously between 0.75 and 1.25Hz.

In conclusion, our findings suggest that the brain encodes and adapts to sensorimotor delays based on the frequency of the ongoing movement rather than in actual time, contrary to previous assumptions.

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