Direct measures of implicit learning hit ceiling within 1-4 trials of training regardless of feedback

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How fast is implicit learning?

People can quickly adapt their hand movements to various perturbations, which is usually attributed to explicit components. However, it is unknown how quickly implicit components of learning emerge, when directly measured as opposed to inferred as a residual aspect of explicit learning, using a two-rate model. Here we investigate the speed at which implicit learning emerges by directly measuring it in two ways, under four various training conditions.

Two-Rate Model for Motor Learning

The two-rate model (Smith et al., 2006; McDougle et al., 2015) sets the motor output on trial t as the sum of a slow and fast process:

$$X_t = S_t + F_t$$

which are each determined by a learning rate L and retention rate R:

$$S_{t+1} = \mathrm{Ls} \cdot e_t + \mathrm{Rs} \cdot S_t$$

$$F_{t+1} = \mathrm{Lf} \cdot e_t + \mathrm{Rf} \cdot F_t$$

Both processes learn from errors on previous trials (e_t) and retain some previous adaptation (F_t, S_t). Constraints: Ls < Lf and Rs > Rf. The model explains a rebound after a brief reversal of the rotation.

Experimental Procedure

Five groups experienced a visuomotor rotation, where their training paradigm and intervening test trial varied. Three training paradigms varied the amount of visual and motor information available, additional description below. The test trial, which was excecuted after every single training trial, was used to probe implicit learning in two ways. Participants in one group completed no-cursor trials, where their hand cursor was not visible during or after the completion of the test trial. The remaining groups had the same test trial, a passive localization trial, where the robot dragged their unseen, right hand, to a location that they would then estimate with their seen left hand.

Continous	Active training with continous feedback and hand localizations.
Terminal	Active training with terminal feedback, hand cursor only visible at the end of the reach trial, and hand localizations.
Exposure	Exposure training with continous feedback and hand localizations. *During training participants' hand was deviated 30 degrees away from the target, while the cursor went directly to the target. Participants had no control over the direction they moved, only the distance.
Variation	Active training with continuous feedback and hand localizations, with a randomly changing rotation size and direction.
No-cursor	Active training with continous feedback and no-cursor reaches.

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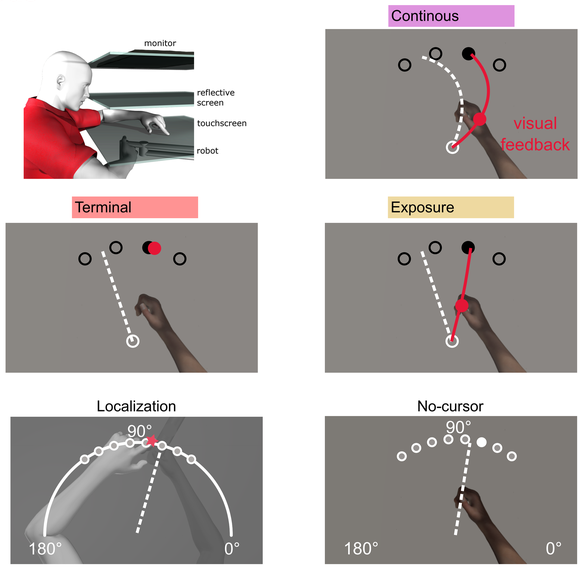
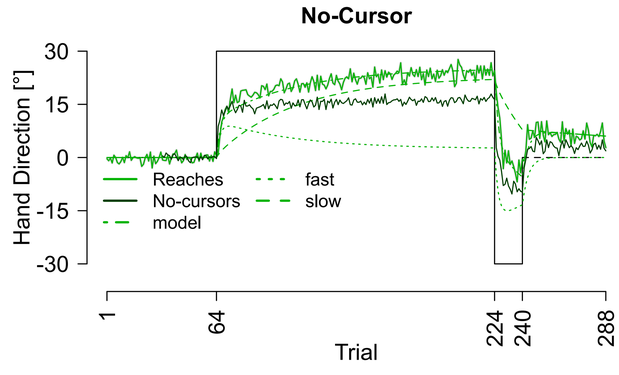
Methods



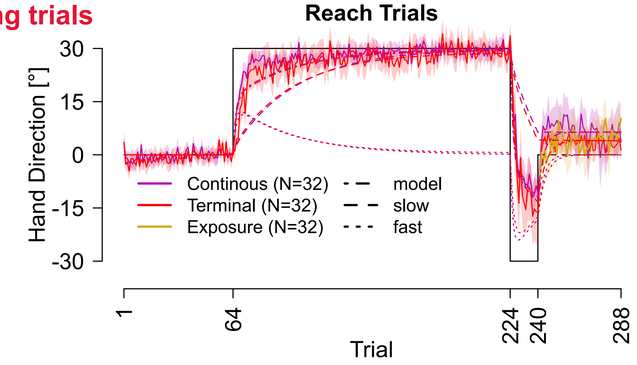
Rate of change

		No-cursor	Continuous	Terminal	Exposure
Reach training	*rate of change*	13.8% [10.7% - 17.7%]	27.0% [20.1% - 32.8%]	14.2% [10.0% - 20.0%]	-
	asymptote	23.2° [22.0° - 24.3°]	28.6° [27.8° - 29.5°]	27.1° [26.1° - 29.7°]	-
	saturation trial	21 [16 - 27]	13 [11 - 17]	20 [14 - 28]	-
Slow process	*rate of change*	3.4% [3.1% - 3.8%]	3.5% [3.0% - 4.1%]	3.3% [3.0% - 3.7%]	-
	asymptote	21.4° [19.8° - 23.0°]	25.2° [22.5° - 27.2°]	25.3° [23.0° - 27.2°]	-
	saturation trial	74 [67 - 82]	66 [56 - 76]	73 [67 - 81]	-
Implicit process	*rate of change*	56.9% [27.4% - 58.5%]	100% [29.0% - 100%]	43.5% [.07% - 100%]	69% [47% - 100%]
	asymptote	15.3° [13.8° - 16.9°]	6.9° [5.9° - 8.0°]	6.3° [5.3° - 7.8°]	5.1° [3.8° - 6.4°]
	saturation trial	3 [1 – 3]	2 [2 – 8]	5 [2 - 24]	3 [2 – 4]

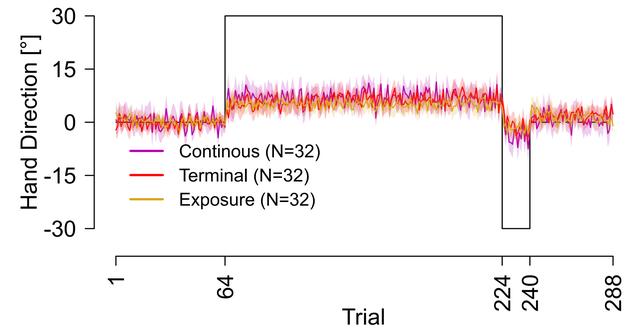
Reach aftereffects emerge and saturate within 3 trials



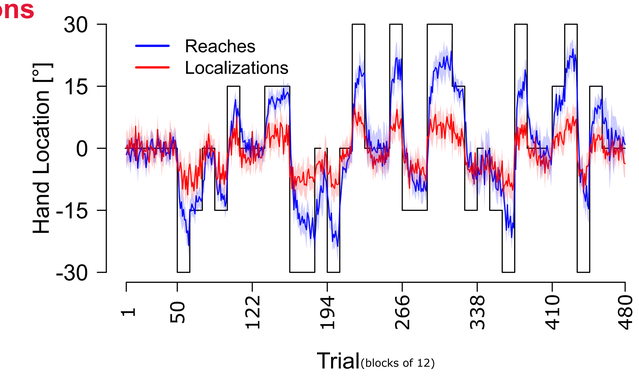
Impoverished feedback slows rate of change in reach training trials



Reducing visual feedback reduces rate of change in hand estimates



Estimates of hand position shift less with successive rotations



Reach aftereffects saturate in three trials

Estimates of hand location shift immediately, even with limited feedback

Implicit adaptation seems to develop independently from explicit adaptation