Motor learning - defined as cumulative continuous change in behavior through practice.

There are many levels of motor learning

motor learning

(1) infants motor learning
- learning transfer function

born w/ lots of neurons → shed over the years. → tuning

This tuning/pruning is important for "learning". - Deficits - neurons don't die - can't learn.

- walking, reaching, manipulating etc

(2) Adult motor learning

a. skill acquisition - sports, music

b. adaptation (to the env., short term?)

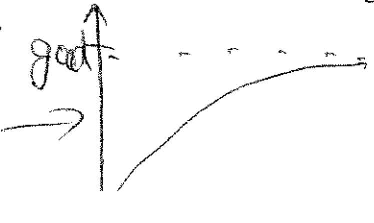
→ one time adaptation - lifting milk carton

→ multi time adaptation
- playing tennis in the wind.

(3) Adult re-learning after neurological or physical injuries
- similar to infant's learning??

quantitatively, what can we see? what can we use to measure learning?

what should this axis be? →



A quick history.

What can be measured depended on the technology available.

First concrete analysis of motor learning (late 1800's → ~1950)

↳ Measured task oriented out come.

ex: - # of steps taken for walking (babies)
- # of balls hit into the tennis court.
- variability of the outcome (e.g. darts)

1950 ~ 1980 More technology → more quantitative measurement

- could measure joint angles (w/ markers/videos) (encoder/pots for joints)
- muscle activation level (EMG)

But there were problems

- skill learning (such as tennis) takes a long time for observation.
- the difference btwn novice & experts was not obvious in joint angles or EMG's.
  - experts didn't have "the movement" as the perfected movement.
  - experts joint angles/EMGs were as variable (if not higher.)

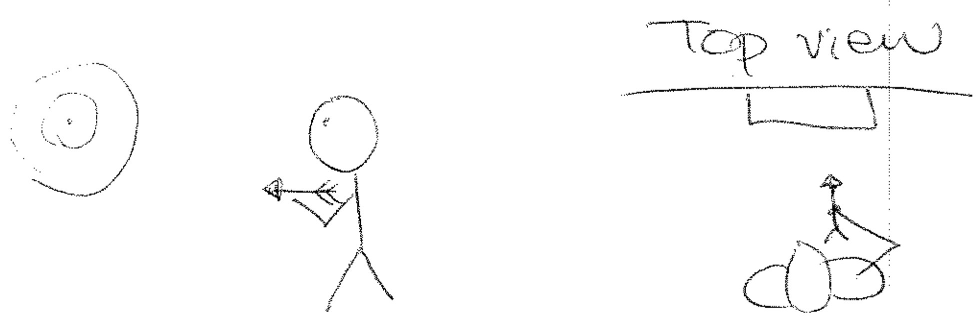
some stereotypical movements

So since 1980's neuroscientists paid attention to multiple time adaptation to external perturbation rather than skill learning because

① changes occur more rapidly
② external perturbation to adapt is controllable.
③ gives insight toward skill learning.

First set of these experiments

Prism adaptation (Jeannerod, 1988)

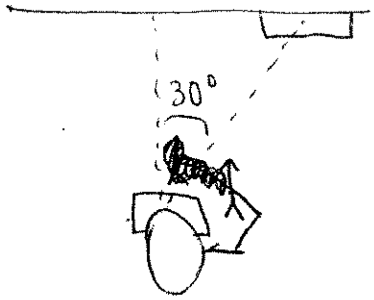


Train w/ No Prism.

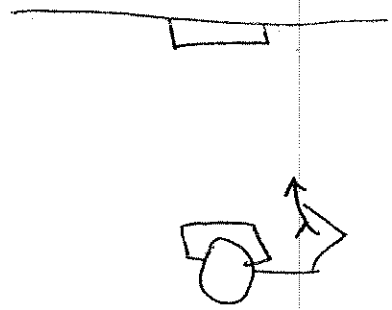
After training → prism that shifts the visual filed by 30°.

Also move the target so it appears 0° from them.

Real

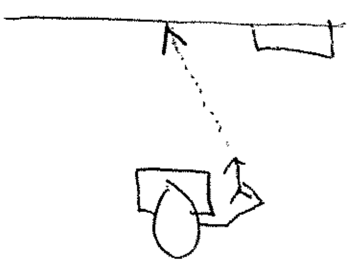


subject's view

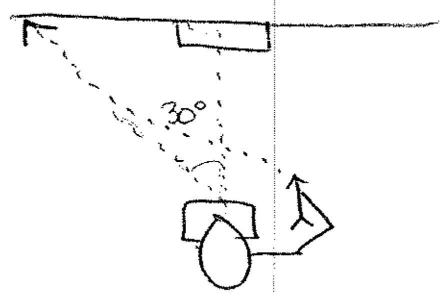


First throw

Real

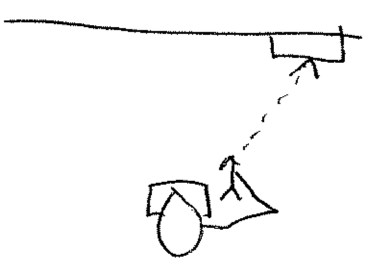


subject's view

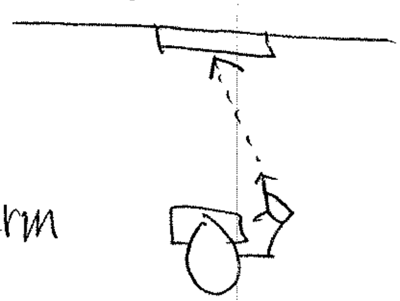


After 50 throws

Real



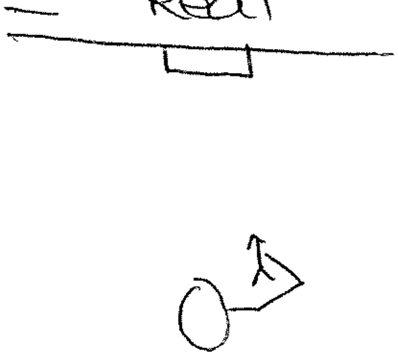
subject's view



when subject's are asked, they don't know their arm is so off!

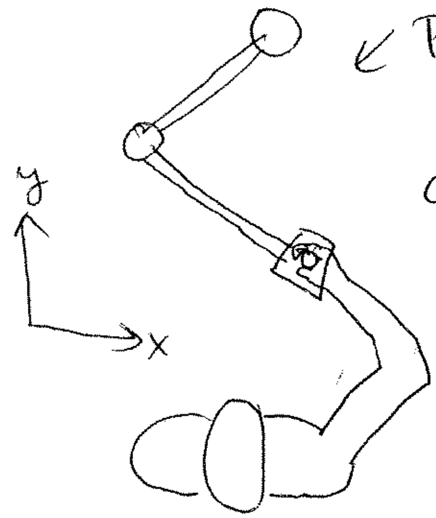
Removal of prism → First throw (after putting target back in place)

Real



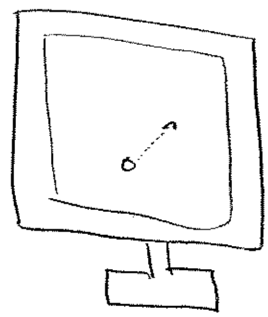
where do you think the dart will go?

In 1993 Shadmehr & Mussa-Ivaldi
Created force-field adaptation paradigm.

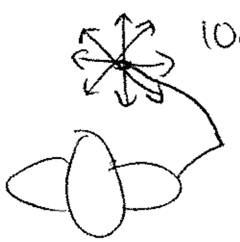


← planar robot that can produce force in the x-y plane

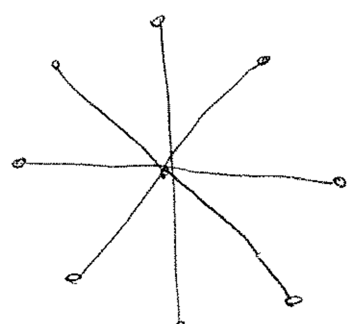
also record movements & display on the computer screen



eight outward movements are executed



10cm long w/ No perturbation.



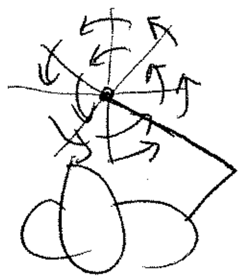
Movements were straight. to the

When an external force field was produced by the robot, the arm movements are distorted. Like swimming in river w/ current or playing tennis in the wind.

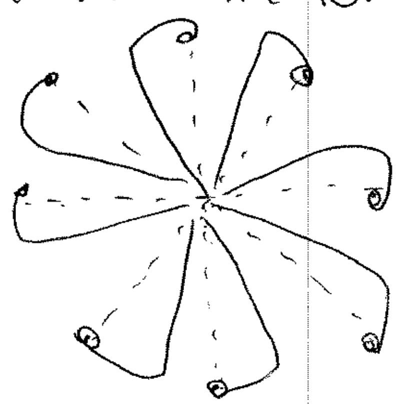
Specifically, Shadmehr & Mussa-Ivaldi applied curl viscous field.

$$\bar{f}_{ext} = \bar{B} \cdot \dot{\bar{x}} \quad \text{where} \quad \bar{B} = \begin{bmatrix} 0 & -b \\ b & 0 \end{bmatrix}$$

Magnitude → prop. to velocity
direction → perpendicular to the movement.



First time in force field

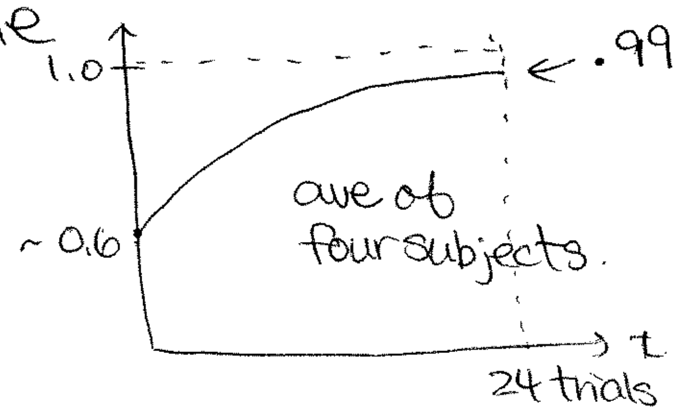


2nd, 3rd & 4th times

24th time / direction

adaptation to the force field – assuming we are optimizing smoothness.

plotted velocity profile
correlation w/ nonperturbed profile

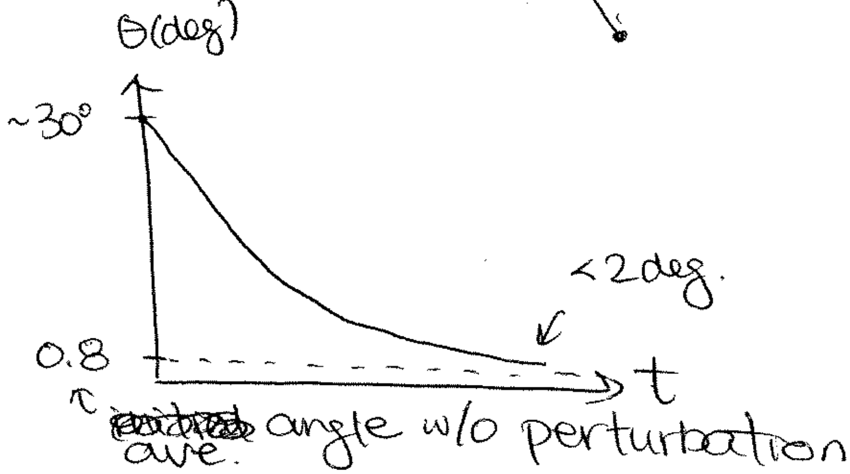


(Mussa-Ivaldi & Gandolfo 1993)

Of course, there are other parameters that may be related to neural adaptation.

Matsuoka (1997)

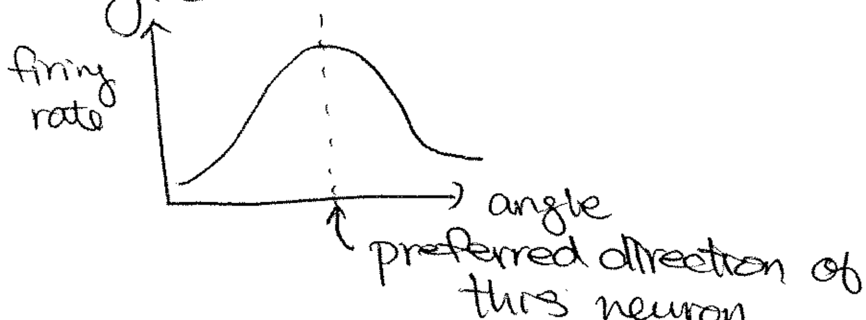
initial moving angle
assuming neurons encode moving directions.



Camillo Padoa-Schioppa (1999)

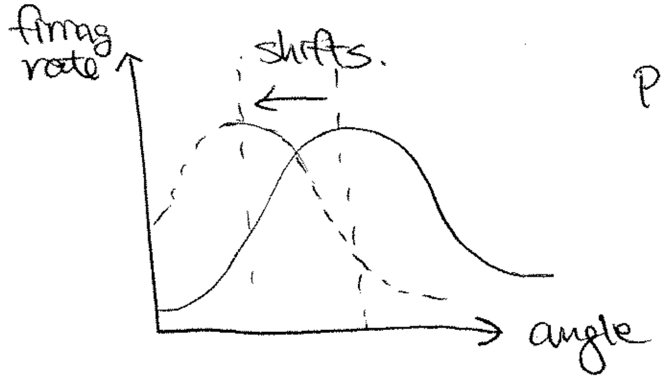
Neuronal preferred direction
(remember Georgopolous's work)

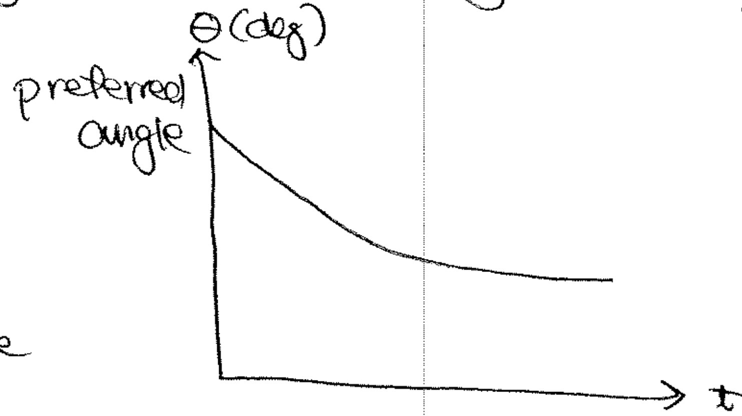
Single neuron



Ambiguity can be eliminated w/ population of neurons.

Recording from a single neuron during training





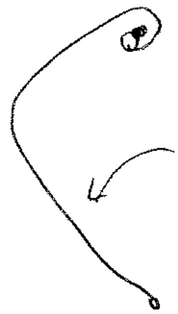
↑ similar to what I found in external measurement.

How do we adapt to the externally applied force field?

$$\underset{\text{traj}}{\begin{bmatrix} \text{shoulder } \tau \\ \text{elbow } \tau \end{bmatrix}} = \underbrace{\qquad\qquad\qquad}_{\text{arm dynamics}} + \underbrace{\tau_{ext}}_{\substack{\text{externally} \\ \text{applied} \\ \text{force field}}} + \underbrace{\tau_{int}}_{\substack{\text{internally} \\ \text{constructed} \\ \text{field}}}$$

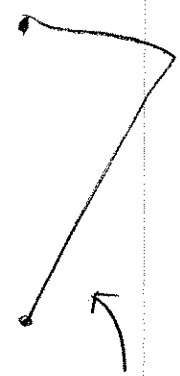
↑ "internal model" of τ_{ext}.

$\tau_{int} = 0$ before training. To observe τ_{int}, we can turn $\tau_{ext} = 0$ suddenly.



after adaptation
in force

after sudden
removal of
force



this change is called
"aftereffect" of the adaptation

Unlearning

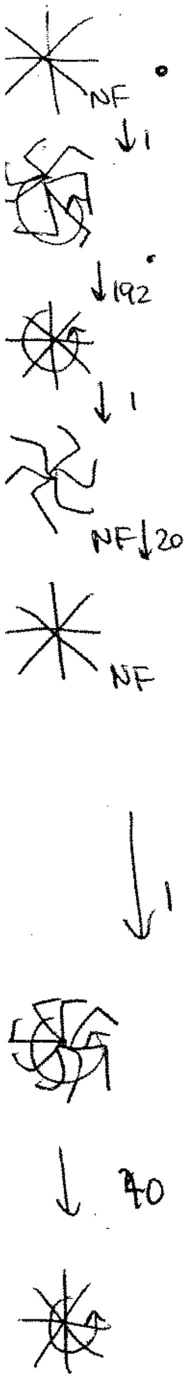
→ For learning, to get to the 90%tile of baseline takes ~20 trials/direction.

→ For unlearning (remove the force), it takes only ~3~5 trials/direction.

What happens if only force trials were experienced, no aftereffect was recorded, went home for the day & came back the next day to see the aftereffect?

guess!

we talked a little bit about unlearning last time.



- Learning the curl force field for the first time takes ~24 trials/direction.
- Returning to the baseline movement in no force condition takes ~3 trials/directio

BUT is this wash out process really unlearning?

- When subjects were exposed to the same force field for the second time immediately following washout, subjects readapt to the ff much quicker than the first time.

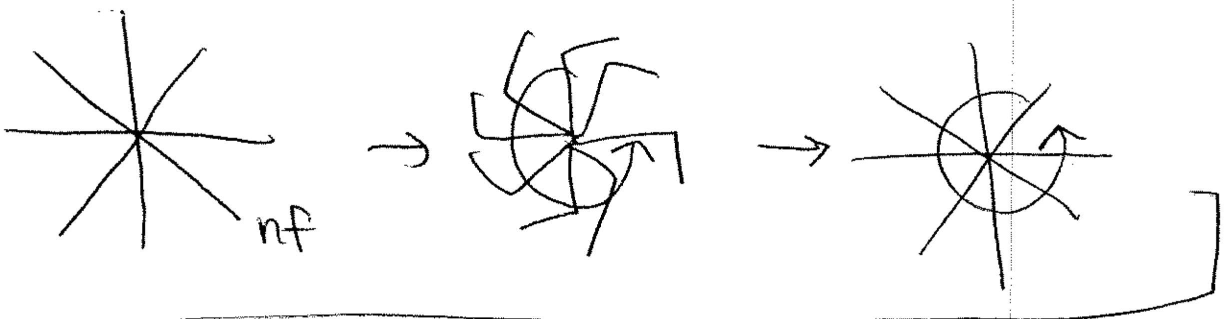
so the previous traing effect was NOT completely unlearned.

So how would we completely washout learned effect & how do we assure retaining learned info?

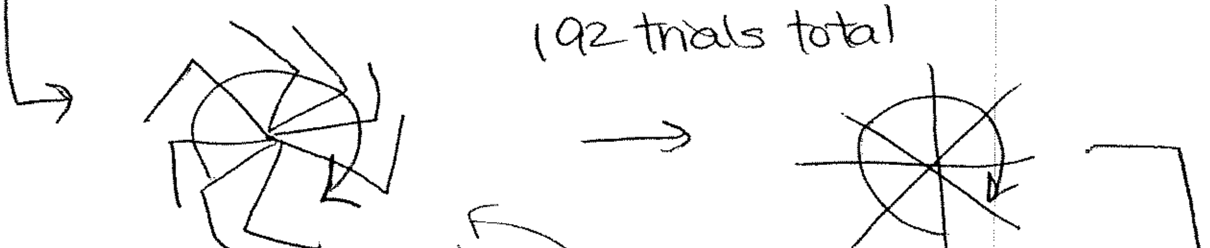
Shadmehr et al. (1996)

1. Use ~~negative transfer~~ retrograde interference to completely erase learned effect.

• 192 trials total $\begin{bmatrix} 0 & -b \\ +b & 0 \end{bmatrix}$



192 trials total

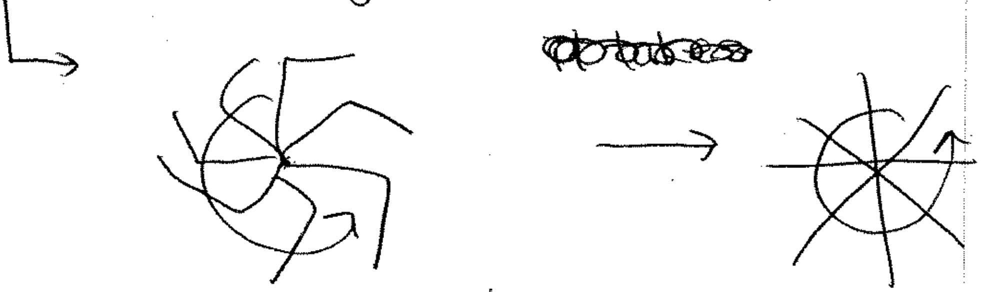


opposite curl field

$\begin{bmatrix} 0 & +b \\ -b & 0 \end{bmatrix}$

subjects do worse in this field than the first f.f. due to "negative transfer".

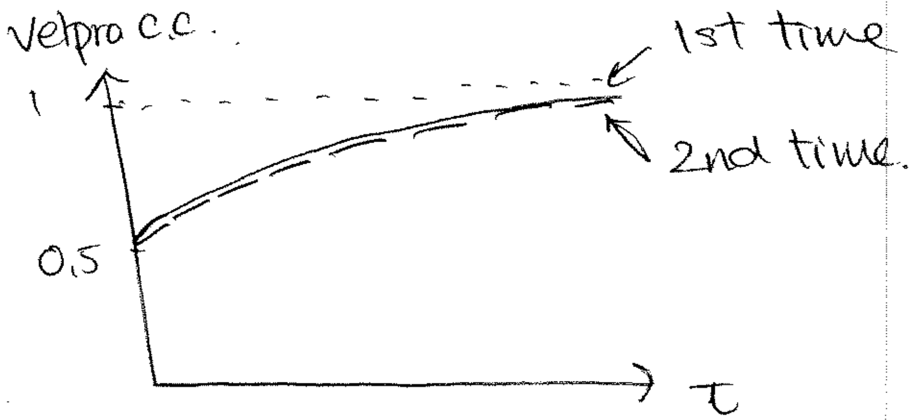
go home, sleep, come back 24 hrs later



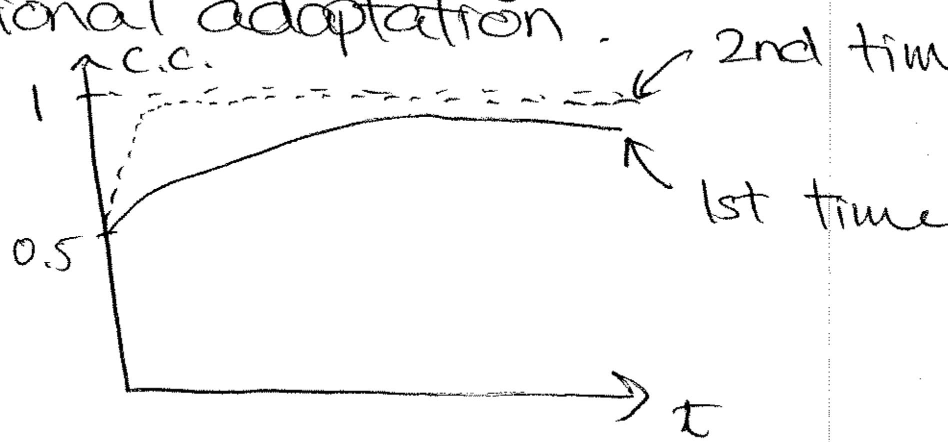
original curl field

how long will it take till these ff is learned?

→ The same length as the first time exposed to the ff.



Last lecture, I told you that if they trained the 1st f.f. only + came back the next day, they exhibit some aftereffects. Not only that, they were able ~~learn~~ readapt to the same f.f. very fast + achieved additional adaptation.

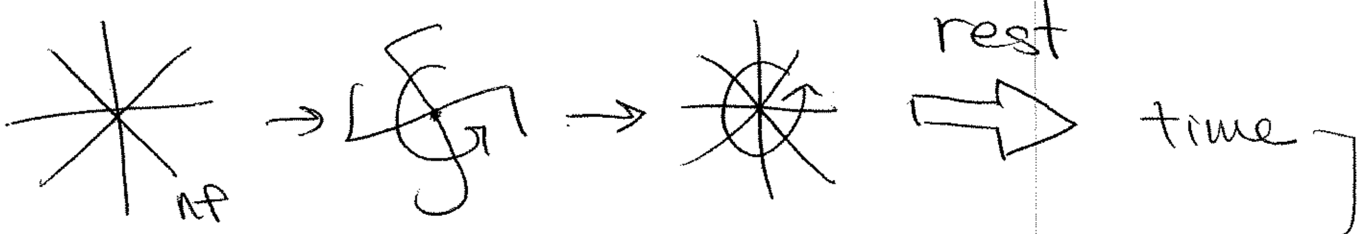


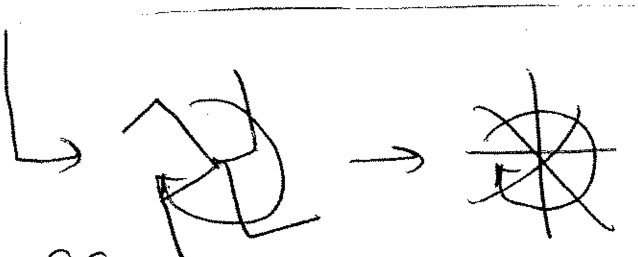
for the same movement. (5)

So is it that if an opposite information is introduced at some point in life time, do the learned information get erased completely?

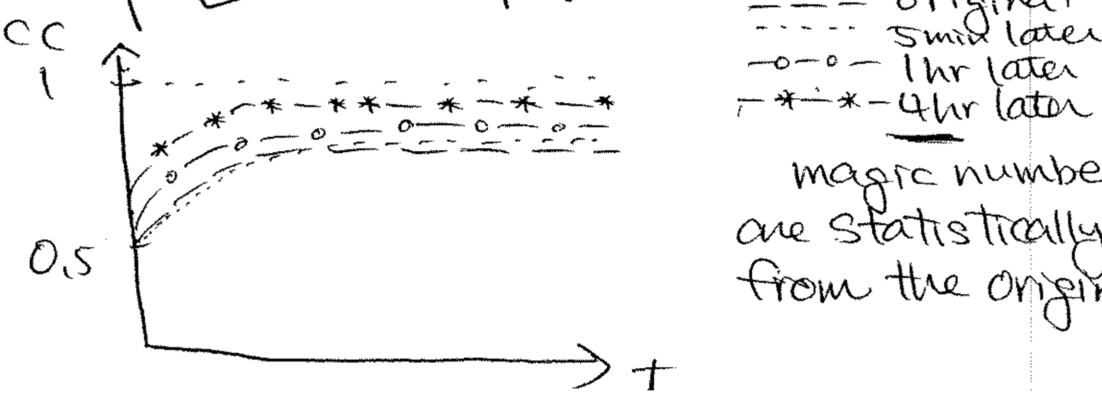
that seems crazy.
So is it time dependent?
If there was some time btwn the original & opposite f.f. training, would it make any difference in retaining the original f.f. information?

yes!





go home, sleep, 24 hours from original exposure...



magic number when curves are statistically difference from the original curve.

This phenomenon is called "consolidation" of memory.

Talking about memory in motor learning is unavoidable yet opens many cans of worms that most motor control community stay away from. (But it's very interesting)

i.e.

what if they spend 4 hrs btwn two f.f. but went home & didn't sleep all night?

↳ the re-adaptation is slower. Memory consolidation is heavily linked to sleep.

Similar but slightly different memory related issue ⇒ mental imaging training

used for sports too.

	1st day	2nd day	3rd day
group1:	original f.f.	nothing	test
group2:	"	came in + visualize the original f.f.	test