Kinematic characteristics and laterality quotient predict interlimb transfer of sensorimotor adaptation

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Introduction

Humans can adapt their reaching behavior to various perturbations such as prismatic deviations, visuomotor rotations or velocity force fields. However, it is unclear whether/why adaptation generalizes to the non-exposed limb.

1- *Paradigmatic Investigation:* Here we hypothesize that **generalization may depend on the visual context.** Indeed, interlimb transfer has been observed without vision of the limb or even with an indirect visual feedback of the limb (e.g., a cursor) [1, 2] while no transfer has been found with vision [3, 4]. The underlying processes may rely on **credit assignment issues**, i.e. the source of errors [5] and/or **cognitive factors** [6].

INFLUENCE OF THE CONTEXT/ CREDIT ASSIGNMENT

Vision	No Vision
↓	↓
Deviations associated to **internal cause**	Deviations associated to **external causes**
↓	↓
Adaptation is effector dependent	Interlimb transfer

Hypothesized relationship between credit assignment and generalization [5]

2- *Idiosyncratic Investigation:* A classification model was developed to investigate whether individual kinematics and subjects' characteristics could be linked to interlimb transfer.

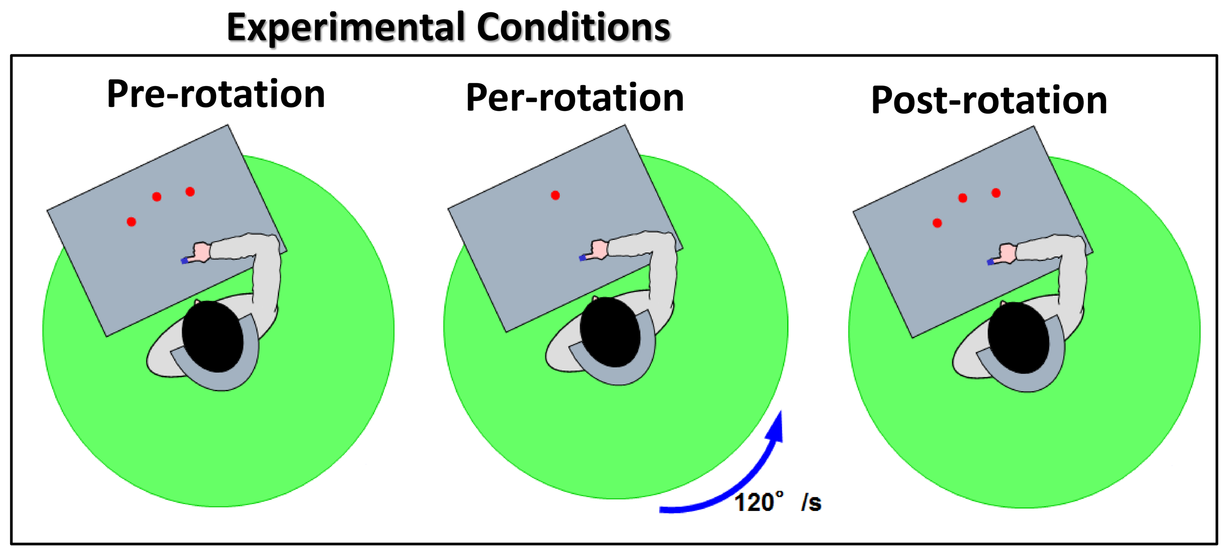
3- *Hypothesis Confirmations:* We tested 2 proprioceptively-deafferented subjects and hypothesized that they would not be able to transfer since 1) proprioception has been shown to be important for updating the internal model of limb dynamics, 2) subjects rely on vision which we hypothesized may prevent interlimb transfer. Also, it allowed us to further test the generalization capacities of the model.

Methods

Two groups of young, right handed adults and a group of 2 deafferented subjects had to reach toward flashed targets on a rotating platform:

Proprioception group (P group)	Vision- Proprioception group (VP group)	Vision group (V group)
N=10, 5 males 5 females mean age : 24.6 years	N=10, 5 males 5 females; mean age : 23.3 years	N=2, 1male (IW) 61 years old 1 female (GL) 65 years old

Experimental Conditions

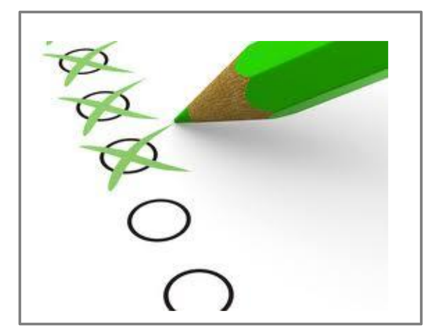


1- Dominant arm (DA)
2- Non Dominant Arm (NDA)
(30 trials each)

3 - Dominant arm (DA)
(100 trials to the central target)

4- Non Dominant arm (NDA)
5- Dominant arm (DA)
(30 trials each)

6 -Questionnaire



(Relative to credit assignment & awareness of errors)

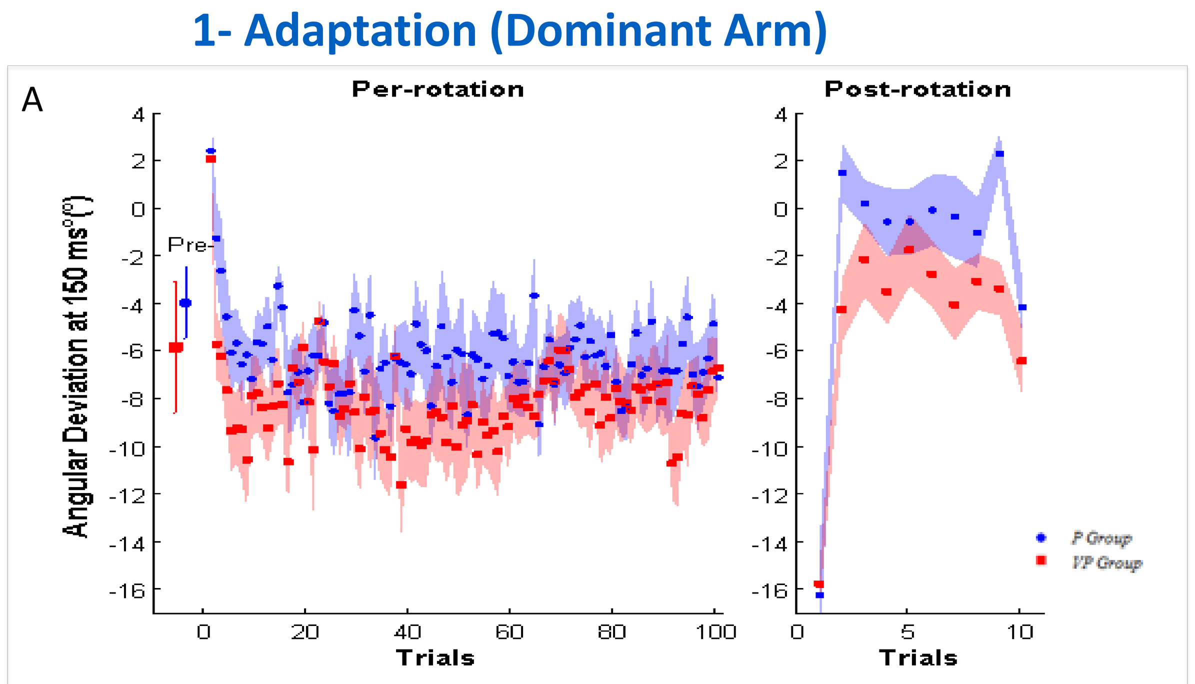
Analysis

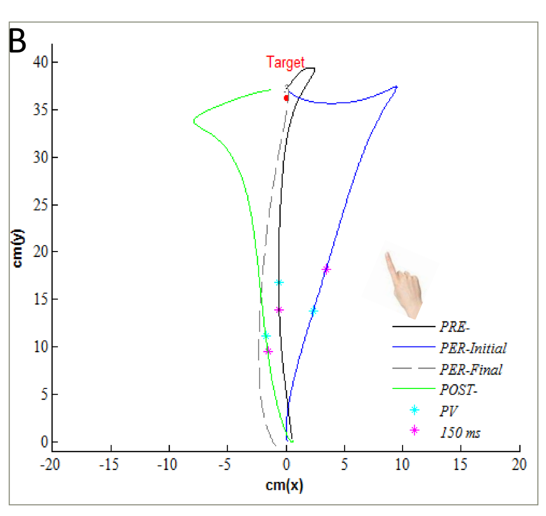
→ Analysis of the adaptation and transfer: **initial movement direction at 150 ms** (°).

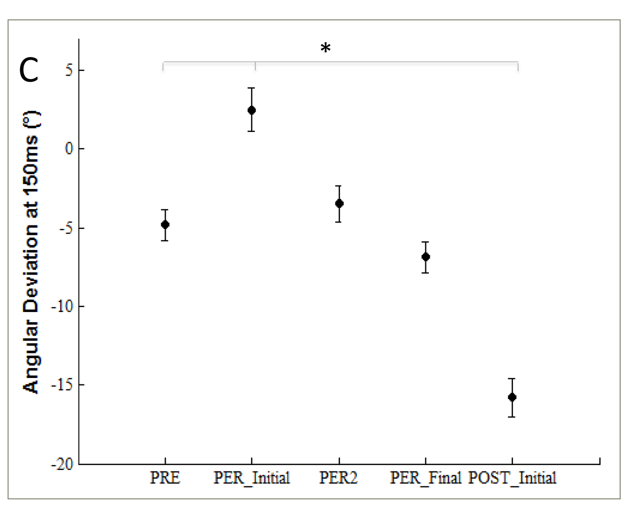
→ Development of a **linear discriminant analysis (LDA)** model to predict interlimb transfer of each subject on the basis of kinematics and subject characteristics. Results are presented with a **receiver operating characteristic (ROC) curve**. It displays the probabilities in term of sensitivity and specificity of the model at each decision threshold (from 1 to 0).

Results

1- Adaptation (Dominant Arm)

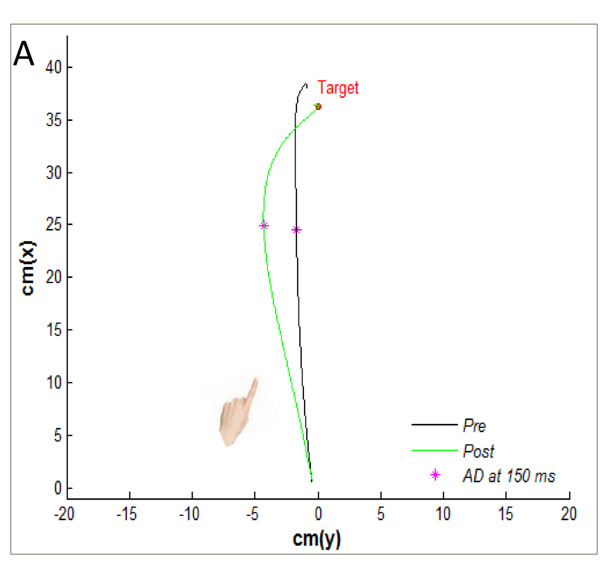


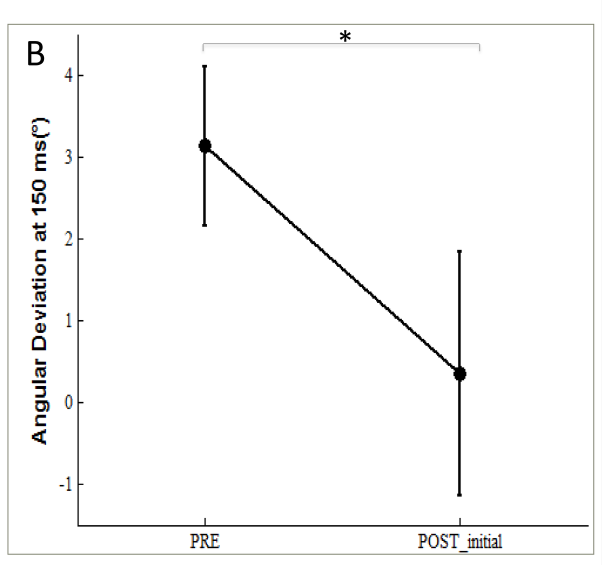




Reaching direction at 150 ms of the DA in each experimental phase
A) Evolution of the initial direction of reaching movements in both groups in Pre-, Per- and Post-rotation phase.
B) Top view trajectories of one subject of the VP group.
C) Mean initial direction (at 150 ms) differed in Pre-, Per-initial and Post-initial (p<.000).

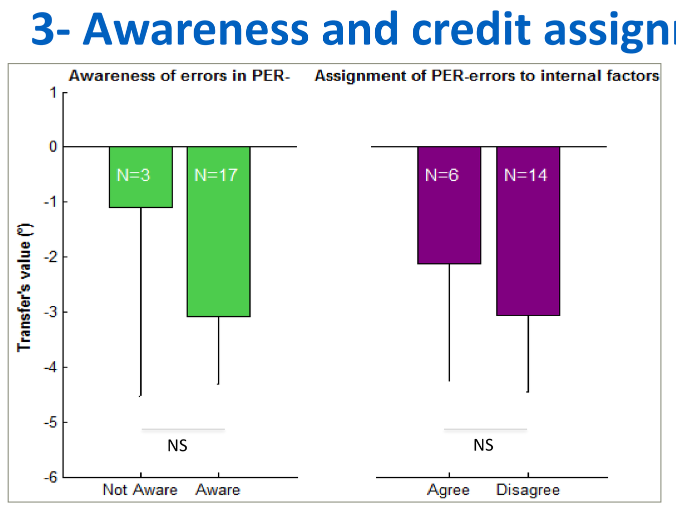
2- Interlimb Transfer (Non Dominant Arm)





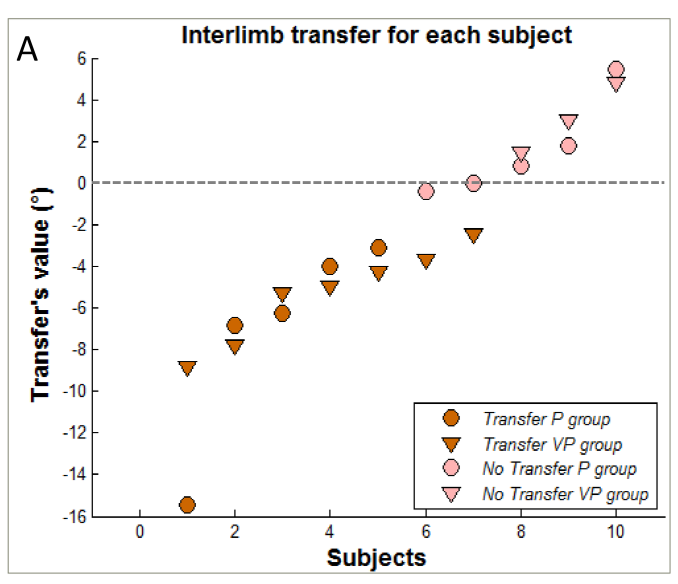
Reaching direction of the NDA in Pre- and Post-rotation phases
A) Top view trajectories of the NDA for one subject of the VP group
B) Mean initial direction (at 150 ms) of the NDA differed between pre- and post-rotation phase (p<.05). There was no significant effect of group and no significant interaction.

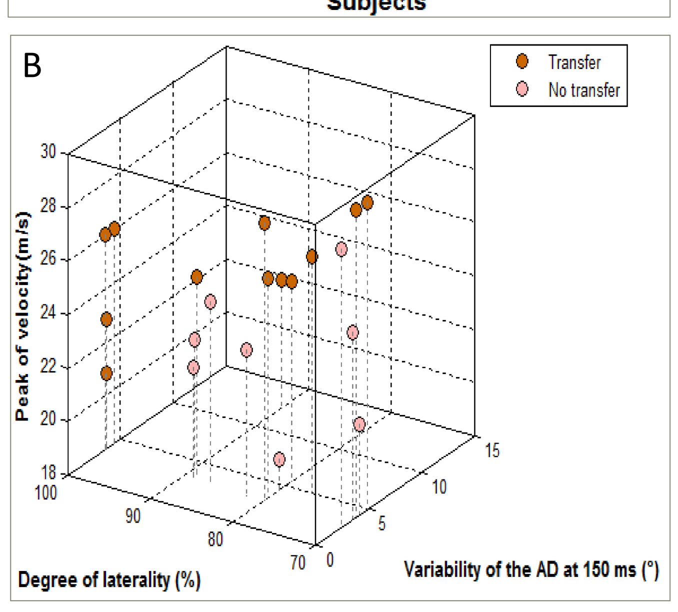
3- Awareness and credit assignment of errors

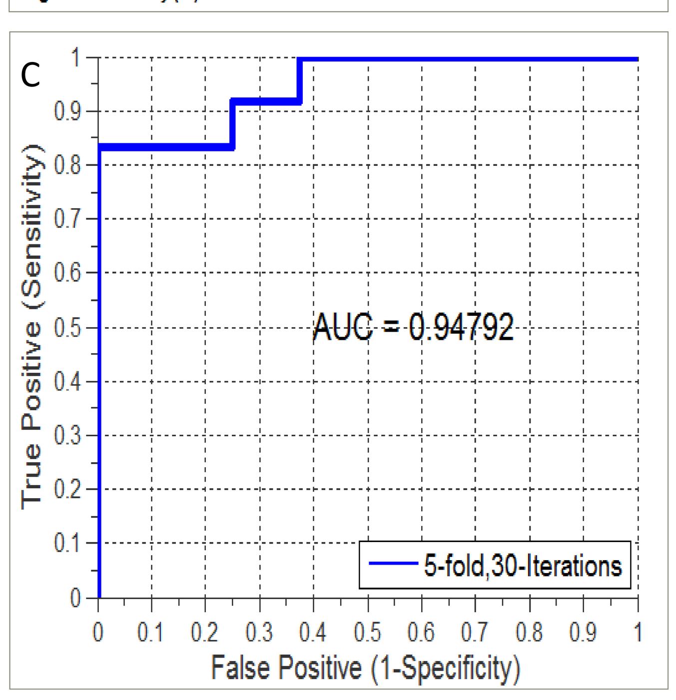


Comparison of the mean of transfer (difference between pre and post) according to awareness and assignment of errors (both in the Per-) to internal factors.

4- Classification Model of Transfer (NDA)

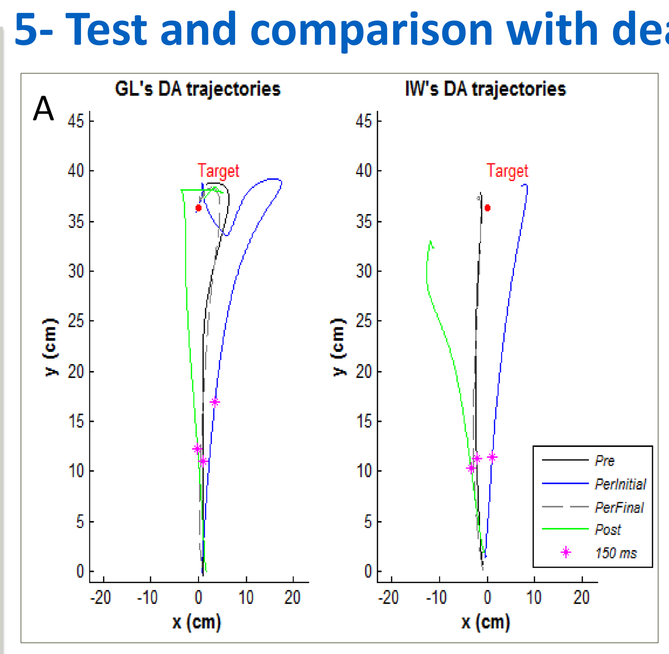


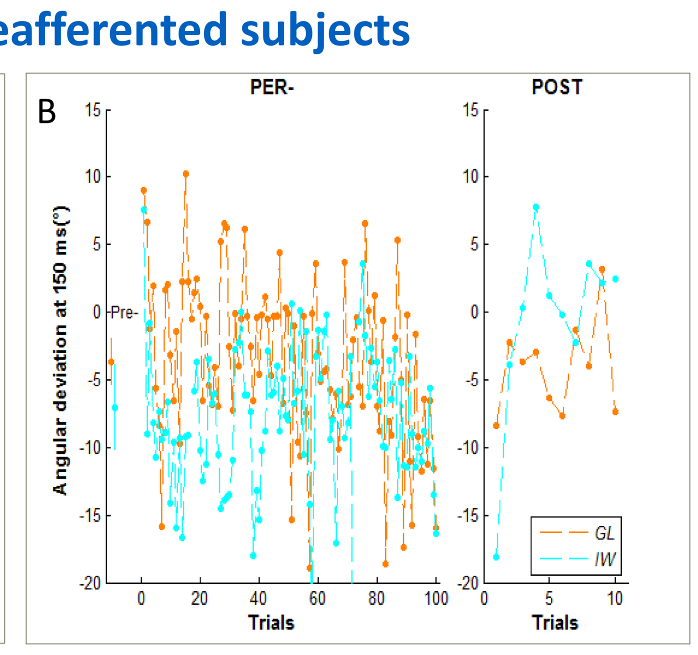


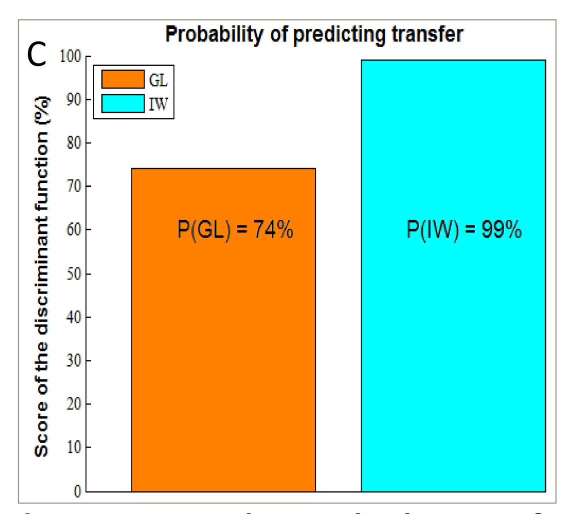


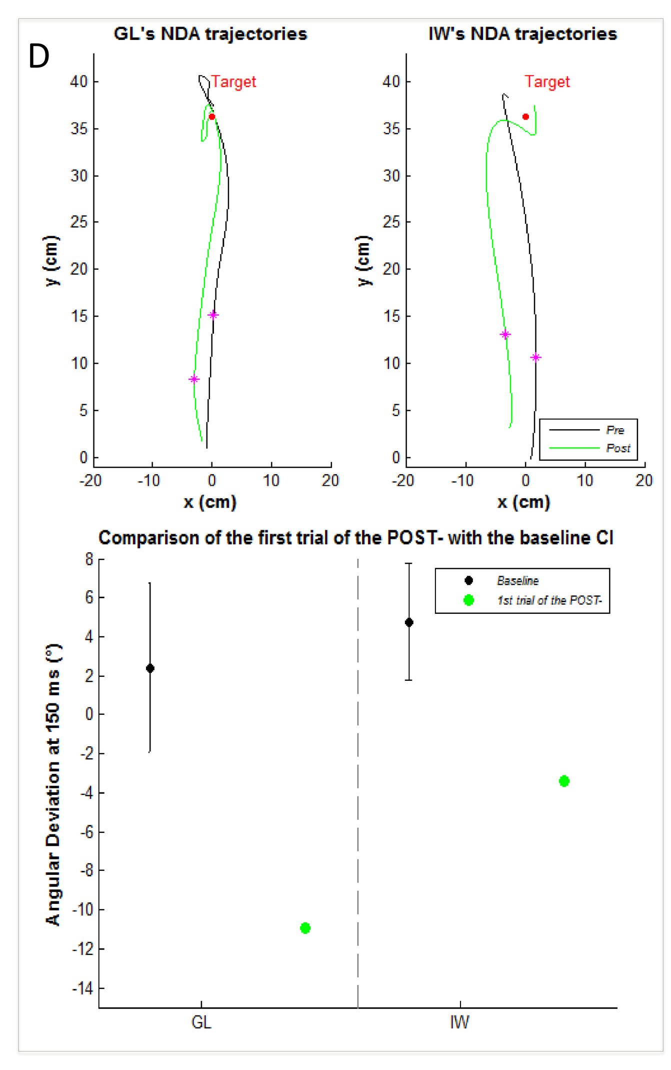
Linear discriminant analysis predictive model of interlimb transfer
A) Representation of each subject's transfer value (difference between the mean of the Pre- and the first trial of the Post-).
B) Representation of the 3 independent predictor variables of the LDA based model (PV, variability of the AD at 150 ms, and laterality quotient) according to the 2 dependent variables (transfer vs no transfer). For each variable higher means are observed in the group transfer.
C) Performance of the model over the whole dataset. The area under the curve of the LDA based model's ROC curve was 0.947, which indicates strong discriminating ability. By extension, both sensitivity and specificity are well balanced through the curve since a high sensitivity (i.e. transfer detection) is not obtained at the cost of a low specificity (i.e. no transfer detection).

5- Test and comparison with deafferented subjects









Adaptation and Interlimb transfer of deafferented subjects
A) DA trajectories viewed from above
B) AD at 150 ms for GL and IW in the 3 experimental conditions for the DA.
C) Representation of GL's and IW's probability to be in the class « transfer » (test dataset) on the basis of the 20 control subjects (training dataset).
D) NDA trajectories. The 2nd figure represents the comparison of the 99% confidence interval of the baseline with the first trial of the Post in term of AD.

Discussion

On average in each group, we observed interlimb transfer to the untrained NDA. The questionnaire analysis showed that conscious awareness, or attribution of trajectory errors to internal causes, did not seem to influence interlimb transfer. Thus, we found no evidence that visual or proprioceptive feedback, or conscious mechanisms determine interlimb transfer.

We noticed a substantial inter-subject variability in transfer and developed a model which correctly predicted the presence or not of interlimb transfer with an accuracy of 95% based on 3 variables: variability of initial movement direction and peak velocity of the DA during the adaptation phase, and laterality quotient. Greater variability [7], peak velocity and laterality quotient predicted interlimb transfer of force-field adaptation.

Thus, in our experiment, parameters based on the subjects and their kinematics explained better interlimb transfer than paradigmatic conditions.

References

[1] P. DiZio, & J.R. Lackner. Motor adaptation to Coriolis force perturbations of reaching movements: endpoint but not trajectory adaptation transfers to the nonexposed arm. *Journal of Neurophysiology*, American Psychological Society, 74(4), 1787-1792, Oct. 1995

[2] J. Wang & R.L. Sainburg. Interlimb transfer of novel inertial dynamics is asymmetrical. J *Journal of Neurophysiology*, American Psychological Society, 92, 349–60

[3] C.S. Harris. Adaptation to displaced vision: Visual, motor, or proprioceptive Change ? *Science*, AAAS, *140*(3568), 812-813, May 1963

[4] M.M. Cohen. Continuous versus terminal visual feedback in prism aftereffects. *Perceptual and Motor Skills*, AmSci, *24*(3c), 1295-1302, June 1967

[5] M. Berniker, & K. Kording. Estimating the sources of motor errors for adaptation and generalization. *Nature Neuroscience*, NPG, 11(12), 1454-1461, Nov. 2008

[6] N. Malfait, & D.J. Ostry. Is Interlimb Transfer of Force-Field Adaptation a Cognitive Response to the Sudden Introduction of Load? J. Neurosci, SfN, 24(37), 8084-8089, September 2004.

[7] H.G. Wu et al. Temporal structure of motor variability is dynamically regulated and predicts motor learning ability. Nature Neuroscience, 17,312-321, December 2014