

# **What Neuroscience Can Tell Us about Human Error in Aviation**

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Professor at ISAE

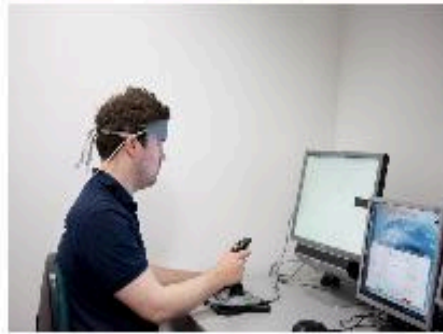
Human Factors and Neuroergonomics Lab



# Preamble: Keywords

- ☀ “stuck in set” perseveration, mental/cognitive flexibility impairment
- ☀ abulia, loss or impairment of the ability to make decisions
- ☀ attentional impairment/”attentional tunneling”, “alarm misperception”
- ☀ stress, emotion
- ☀ ...

## Neuroergonomics: "From laboratory to everyday activity"



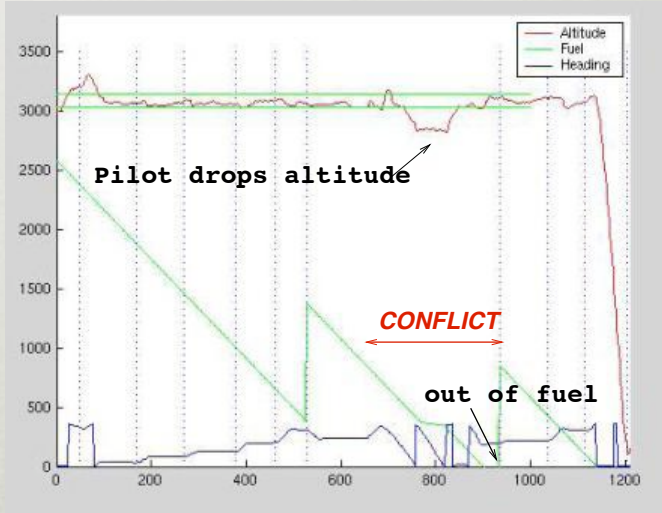
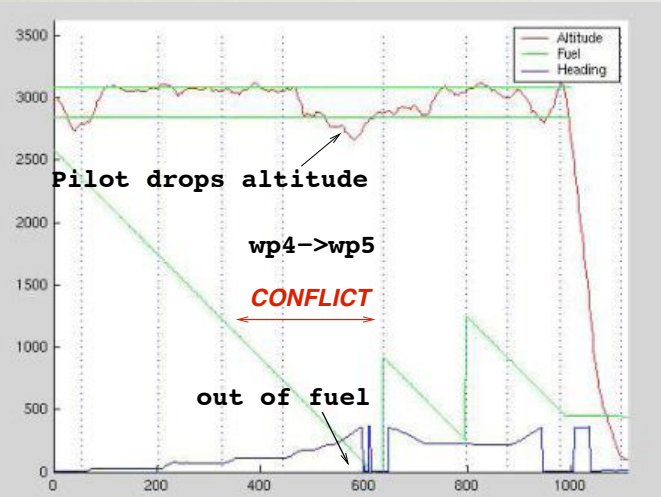
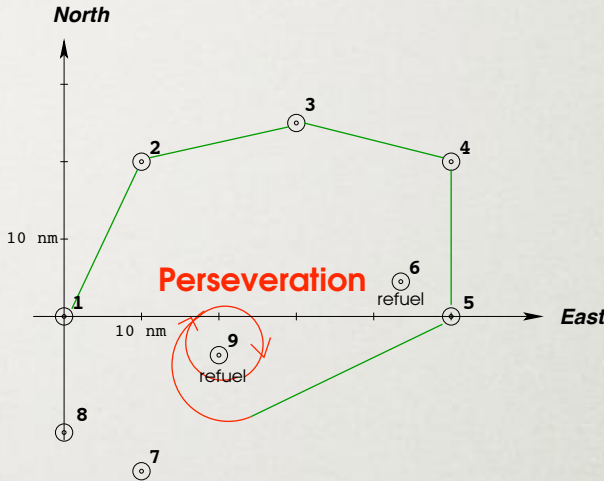
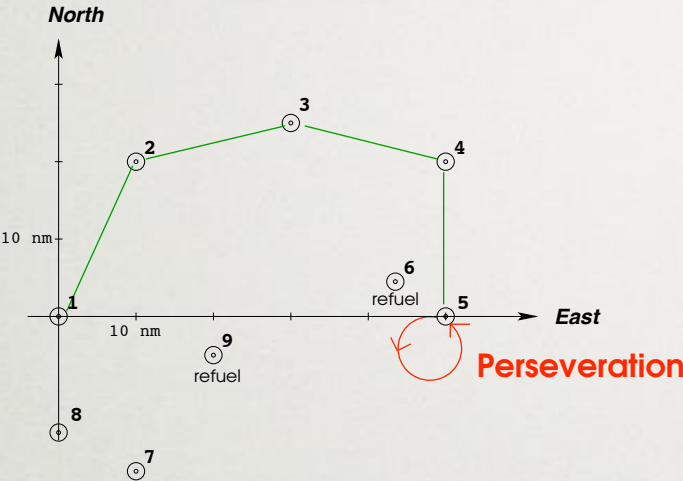
**AXA**  
Research Fund  
Through Research, Protection

- Since 2004, ISAE is developing an expertise in Neuroscience for Human Factors
- A pluridisciplinary team :
  - 3 permanent members (1 Professor, 1 Associate Professor, 1 Research engineer)
  - 7 PhD students (Supaero, X)
  - 4 post-doctoral fellows and 2 associate researchers
- Expertise : Neuroscience, Human Factors, Psychophysiology, Signal Processing & Algorithm, Experimentation

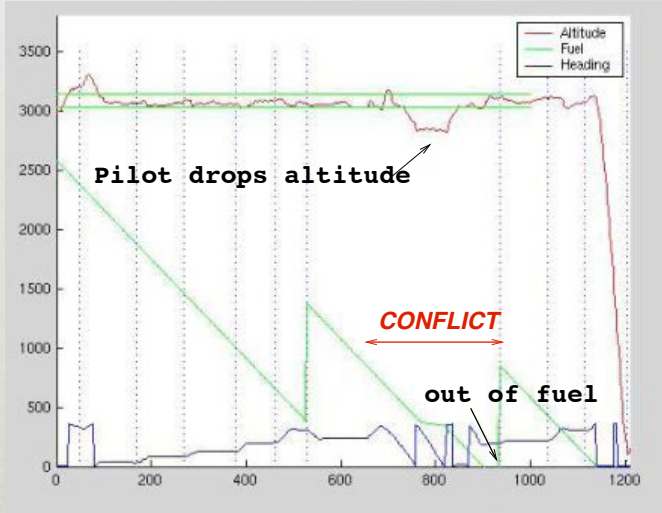
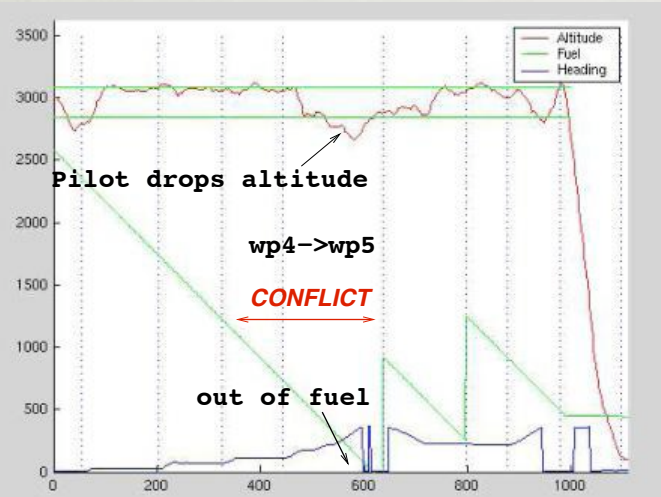
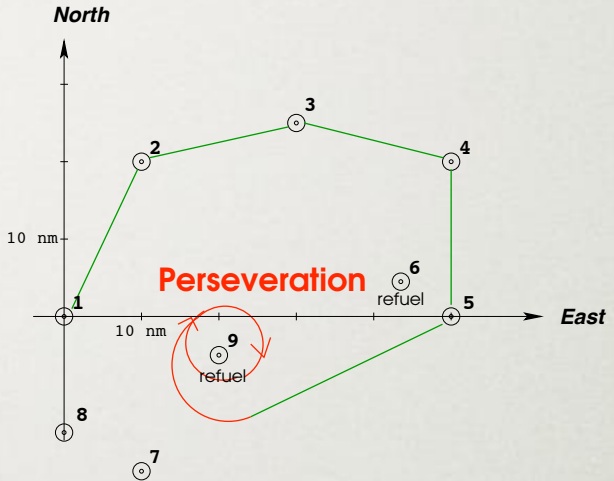
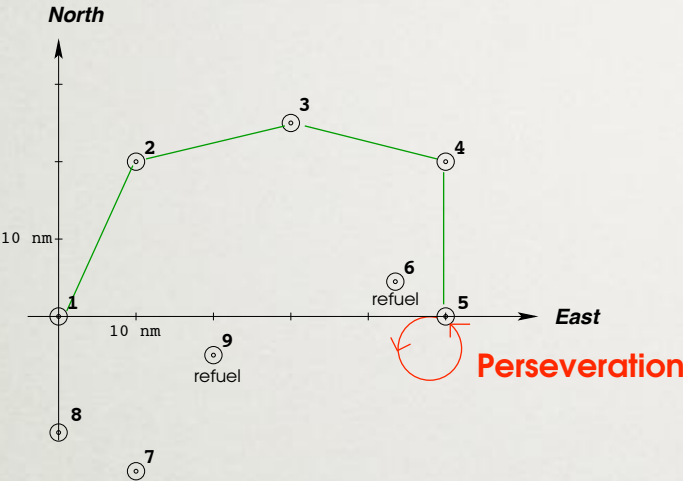


National Institute of  
Information and Communications Technology

# Preamble



# Preamble




All data (tactical situations, heading...) were available in the user interfaces !!


[Dehais et al., 03, 07, 09]

# Preamble: fixation errors

 Fixation errors [Keyser, 90]:

 type 1: the human operator is unable to make up their mind to achieve their current goal

 type 2: the operator keeps on doing the same action sequence without any control

 type 3: the operator has over confidence in their strategy and neglects or does not trust any external



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☀ type 2: the operator keeps on doing the same action sequence without any control

☀ type 3: the operator has over confidence in their strategy and neglects or does not trust any external

high workload,  
stress, hypovigilance

# Preamble: the cognitive continuum

☀ The “cognitive continuum” hypothesis [Pastor, 00]  
dysexecutive syndrome [Eustache, 00] (e.g. Parkinson  
disease)

☀ aboulia

☀ perseveration on psychomotor response

☀ incapacity to adapt to changes

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an inhibition impairment caused by irremediable loss of an associated neural network or a temporary loss of an executive function induced by stress and emotion [Simpson&al, 2001]

**Emotion, stress  
and decision making**

# Emotion and decision making

## (PhD thesis - M. Causse 2006-2009)



*“Persévération”*



August 2005



May 2006



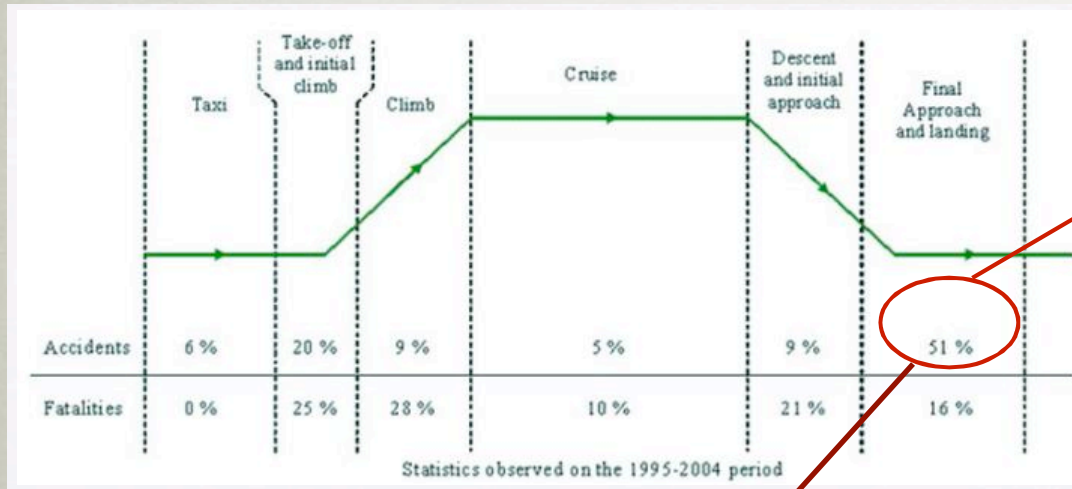
July 2007

### ☀ Emotional bias :

- ☀ economical/ passengers pressure
- ☀ aversive situation
- ☀ uncertainty & complexity
- ☀ a defeat...

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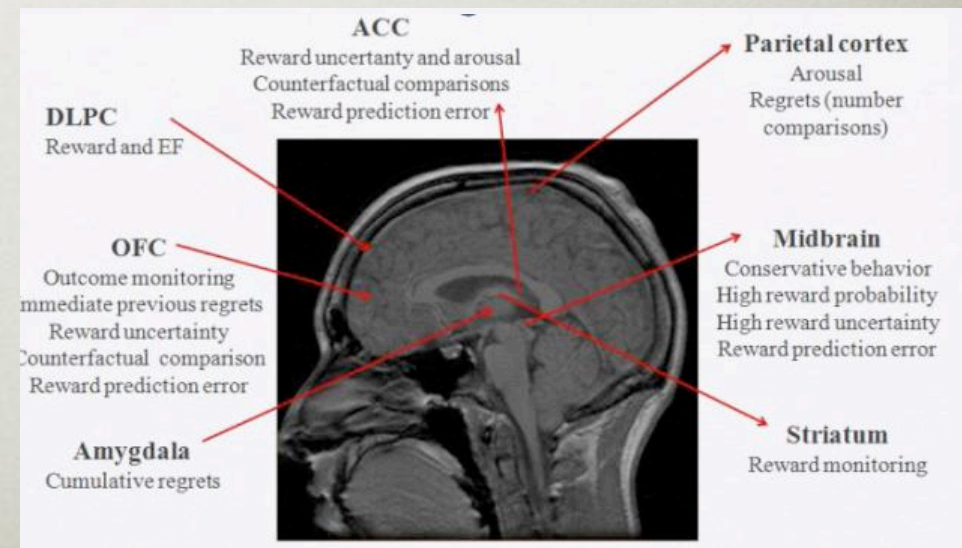
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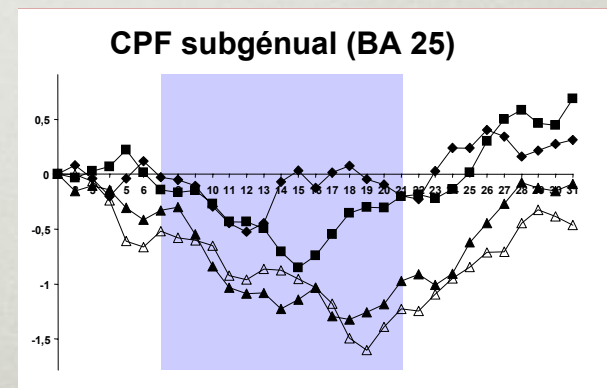
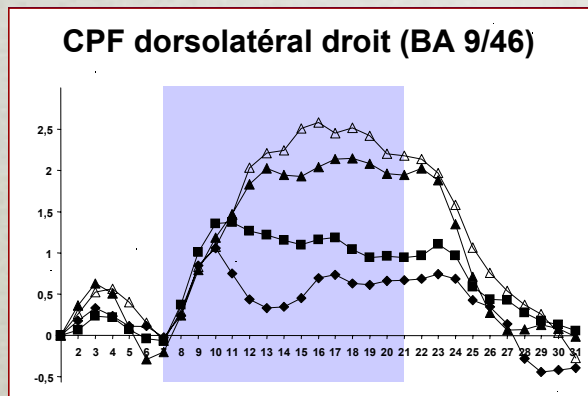
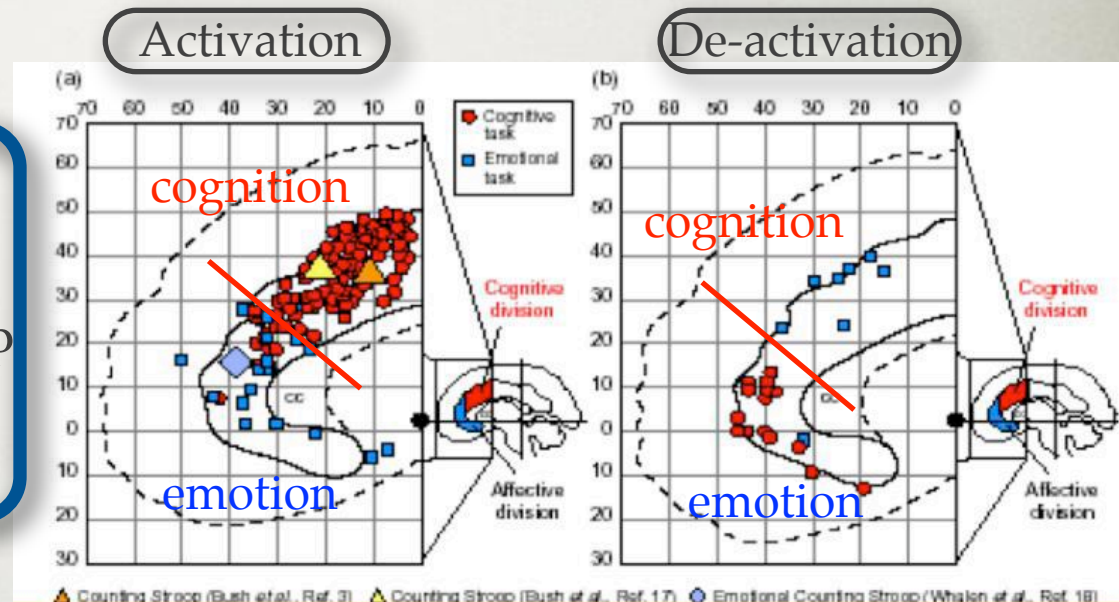
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# Emotion and decision making : The cognition/emotion “shift” hypothesis

- ☀ G. Bush & al, 00 : cognitive stroop task- “2 2 2”
- ☀ Whalen & al, 98 : “emotional stroop task - “murderer murderer murderer”



Pochon et al 2002 : effects of motivation on cognition

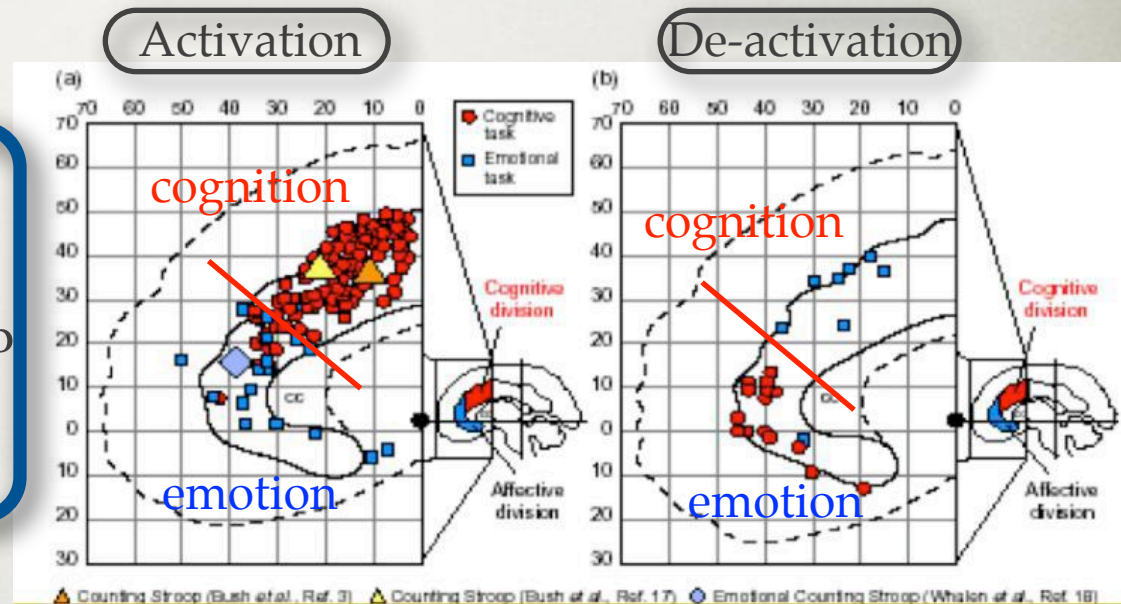
“Cold”

vs.

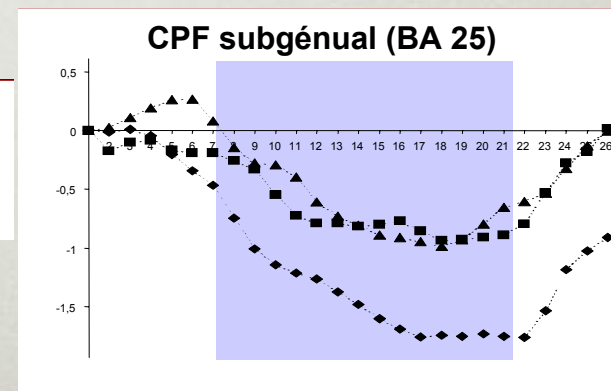
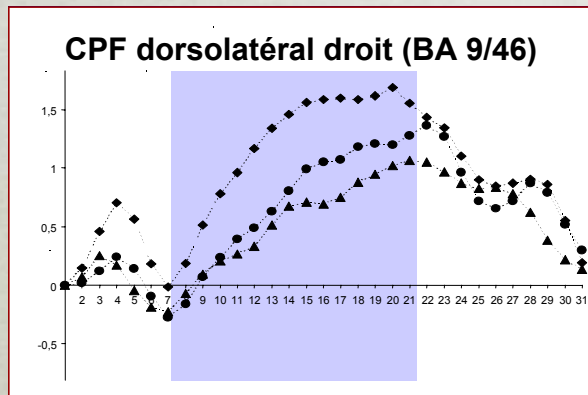
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Anterior Cingular Cortex (ACC)



Pochon et al 2002 : effects of motivation on cognition

“Cold”

vs.

“Hot”



# Emotion and decision making (PhD thesis - M. Causse 2006-2009)



Aeronautical situation



Laboratory

Rational decision making under uncertainty and incentive conditions

# Emotion and decision making

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Rational decision making under uncertainty and incentive conditions

- ☀ fMRI protocol
  - ☀ monetary incentive vs. neutral
  - ☀ uncertainty is manipulated

# Emotion and decision making

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Laboratory

### Rational decision making under uncertainty and incentive conditions

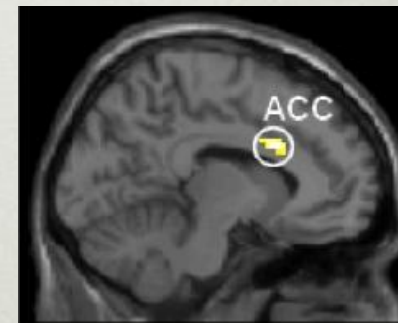
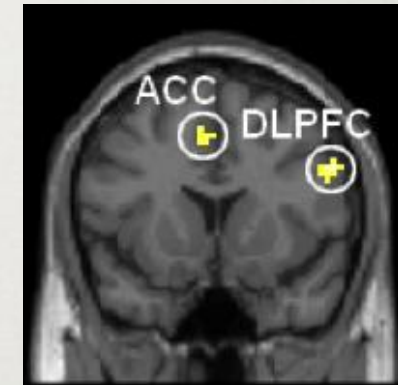
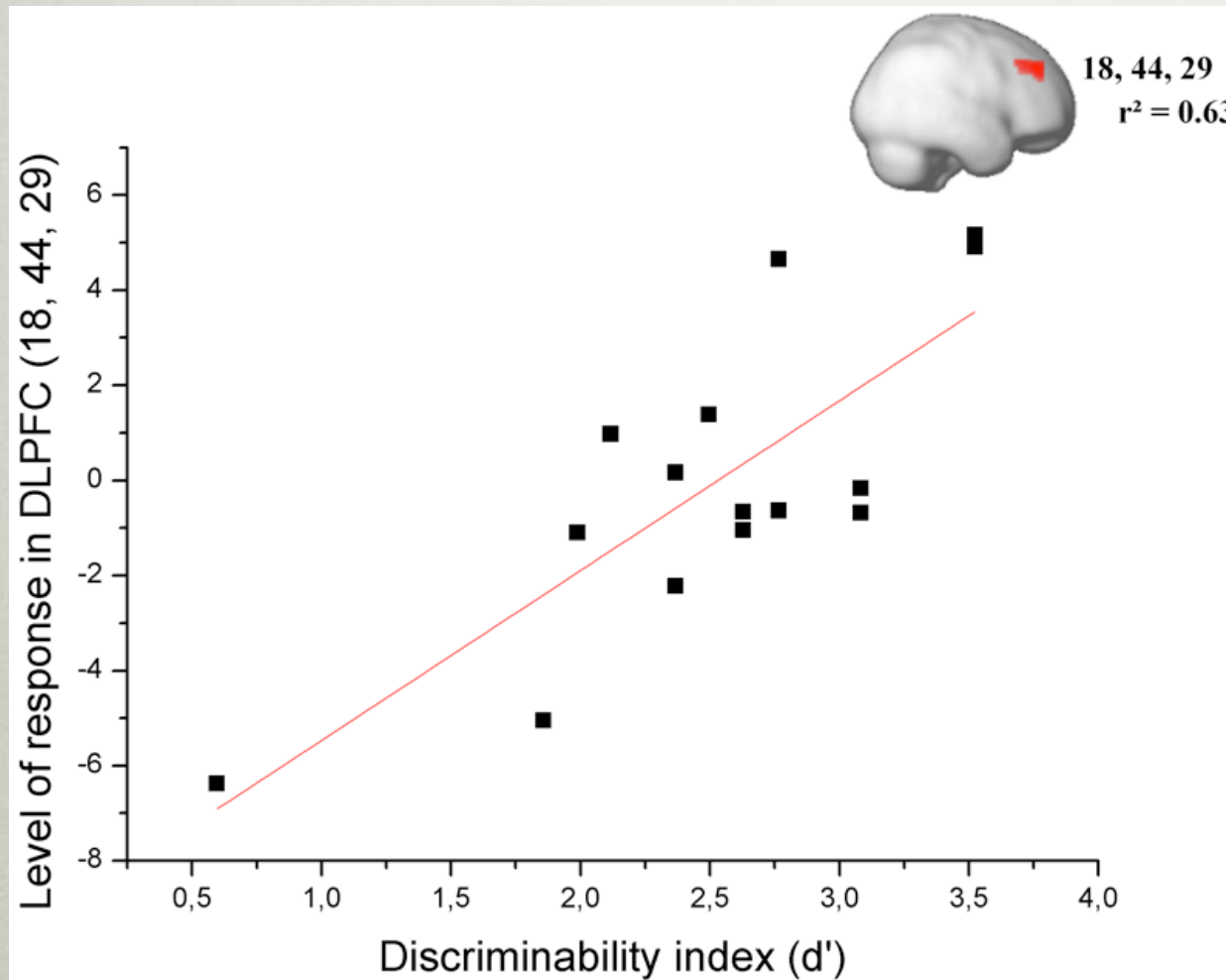
- ☀ fMRI protocol
  - ☀ monetary incentive vs. neutral
  - ☀ uncertainty is manipulated



Analysis of the brain networks involved during “the shift”

# Emotion and decision making

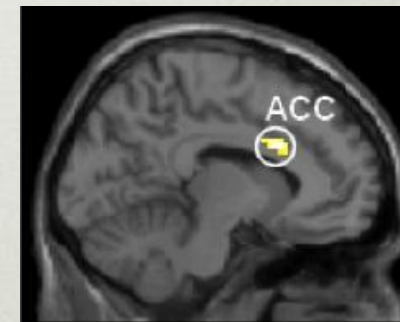
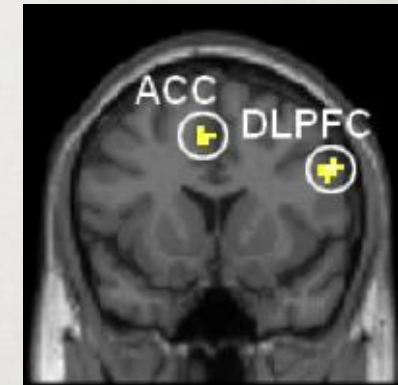
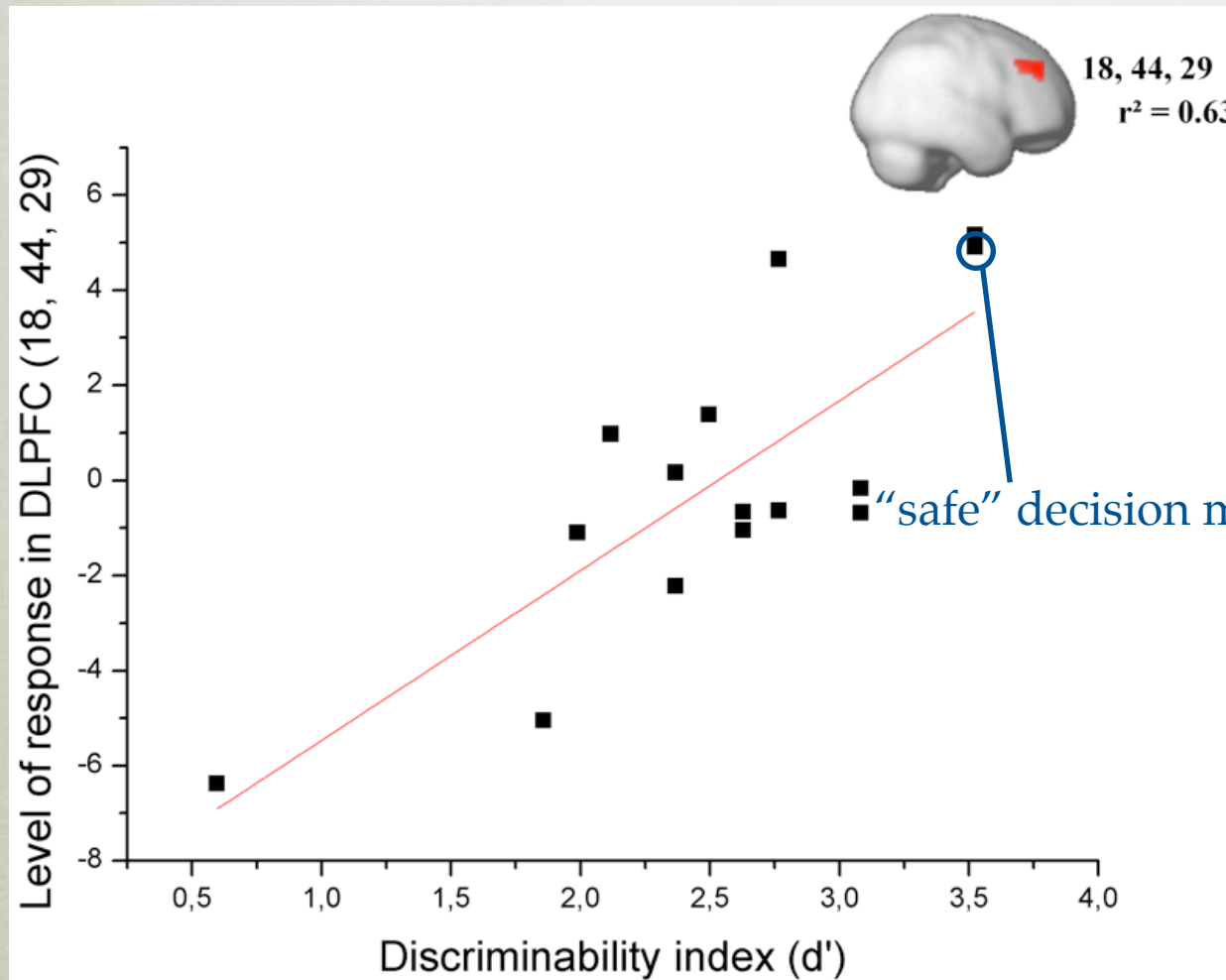
(PhD thesis - M. Causse 2006-2009)



[Causse et al, Neuroimage, 2013]

# Emotion and decision making

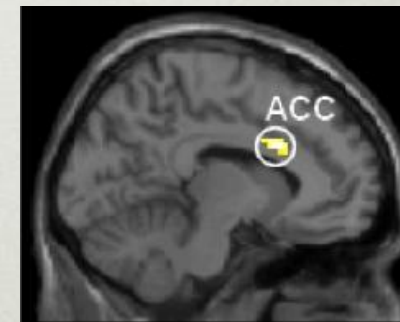
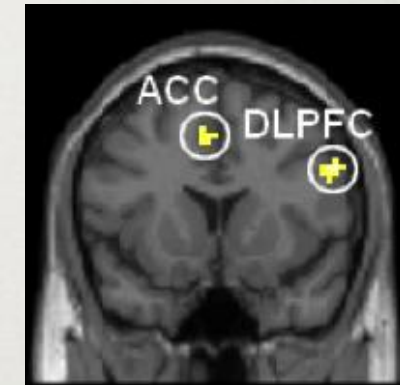
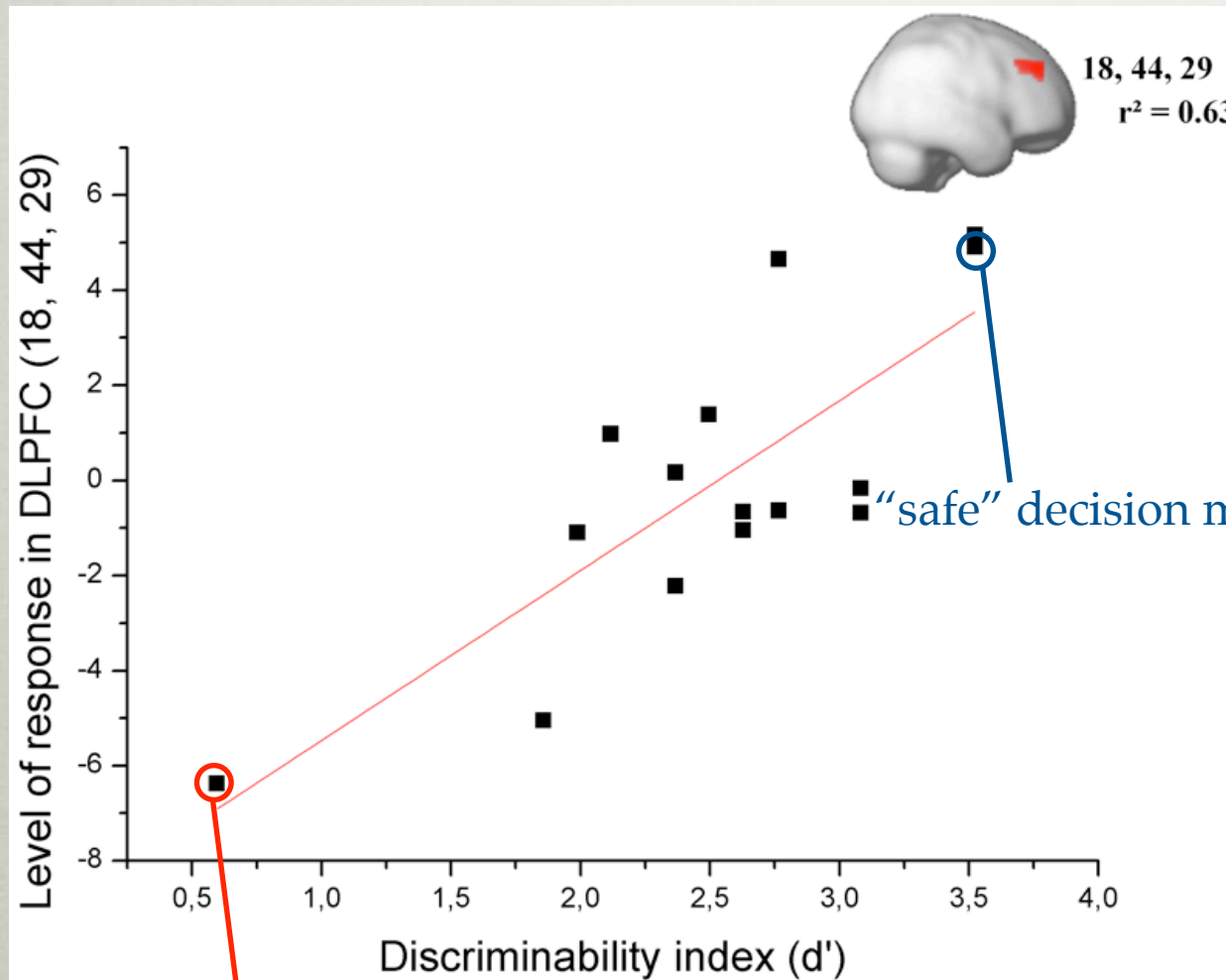
(PhD thesis - M. Causse 2006-2009)



[Causse et al, Neuroimage, 2013]

# Emotion and decision making

(PhD thesis - M. Causse 2006-2009)



“safe” decision maker

“risky” decision maker

[Causse et al, Neuroimage, 2013]

**Mental workload**

# **Mental workload and executive functioning**



# Mental workload and executive functioning

- ☀ Pre Frontal Cortex (PFC) activation during cognitive “saturation” situations:
  - ☀ fatigue : PFC deactivation [Smith & al, 99,05] (EEG)
  - ☀ stress : DLPFC deactivation and WM impairment [Qin et al, 09] (fMRI)
  - ☀ emotion : DLPFC deactivation [Simpson et al, 2001], WM impairment [Dolcos, 06] (IRMf)
  - ☀ multi-tasking : DLPFC deactivation [Goldberg et al, 98] (IRMf) ≠ hyper-activation [Jaeggi et al, 03]

# **Mental workload and executive functioning**

**Phd thesis G. Durantin (2012)**

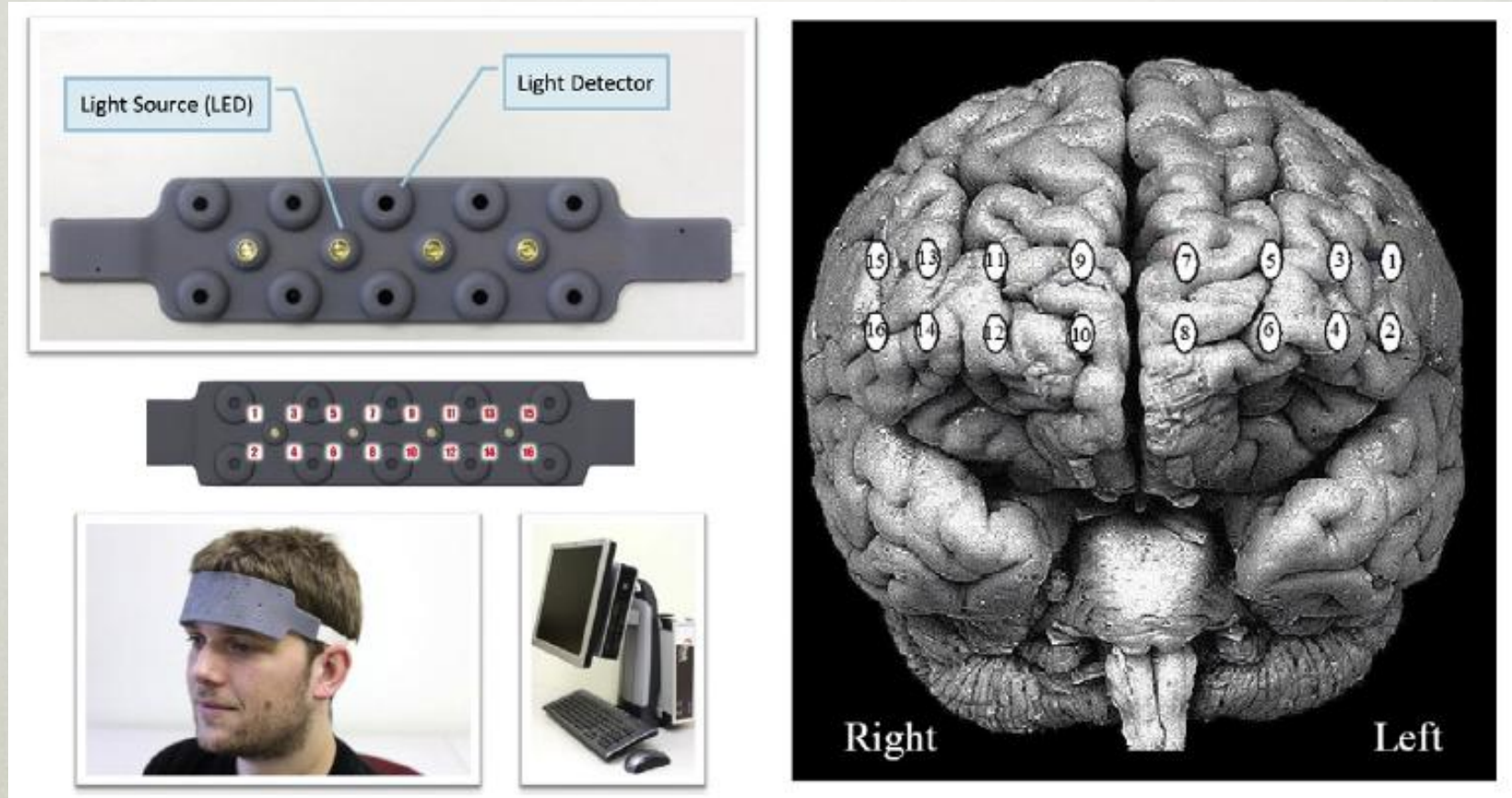
# Mental workload and executive functioning

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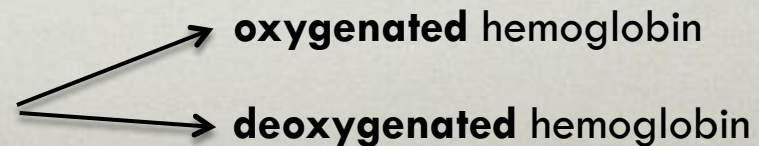
- ☀ fNIRS: functional Near Infra Red Spectroscopy
  - ☀ portable system for measuring mental workload under lab & field conditions [Ayaz et al, 2011]
  - ☀ safe, user friendly, 'low cost' fMRI:
    - ☀ cerebral hemodynamic response: changes in blood oxygenation (HbO<sub>2</sub> converts to HHb)
    - ☀ correlated with fMRI measurements [Cui et al, 2011]
  - ☀ good spatial resolution compared to EEG (1 cm<sup>2</sup>)
  - ☀ slow optical signal: poor temporal resolution - hemodynamic response

# Mental workload and executive functioning

## Phd thesis G. Durantin (2012)



Measurement of **blood concentrations**



# Mental workload and executive functioning

## Phd thesis G. Durantin (2012)

Increased oxygenation with neuronal activity

☀ Aviation: task difficulty (landing/crosswind)  
[Takeuchi, 11]



# Mental workload and executive functioning

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- ☀ Aviation: task difficulty (landing/crosswind) [Takeuchi, 11]
- ☀ UAV: sustained attention [Menda et al., 11]
- ☀ ATC: task difficulty (# of planes) [Ayaz et al., 11]

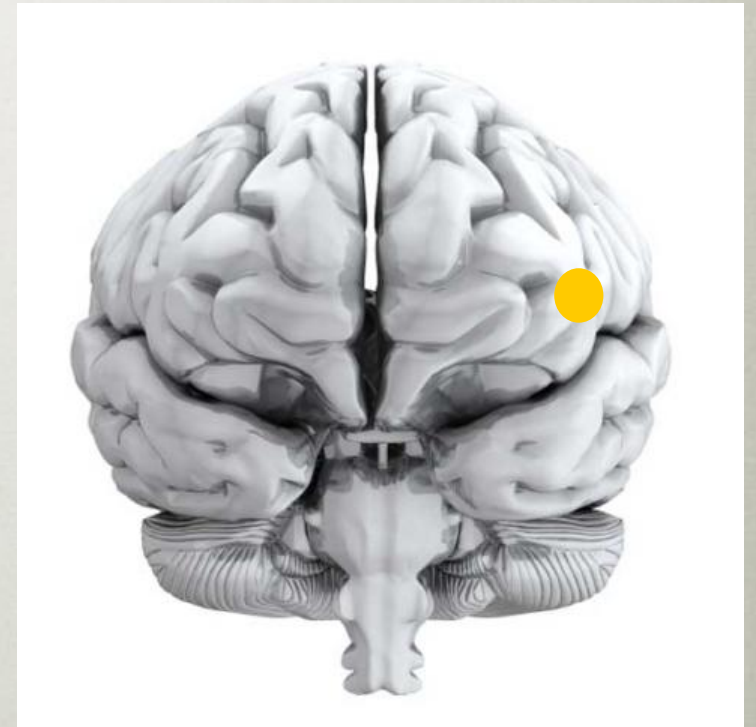


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- ☀ ATC: processing load [Ayaz et al., 11]



# Mental workload and executive functioning

## Phd thesis G. Durantin (2012)

- ☀ “Ecological” task : working memory task [Causse et al, 2011, Taylor et al, 05] and flying task  
Interdependent Tasks





# Mental workload and executive functioning

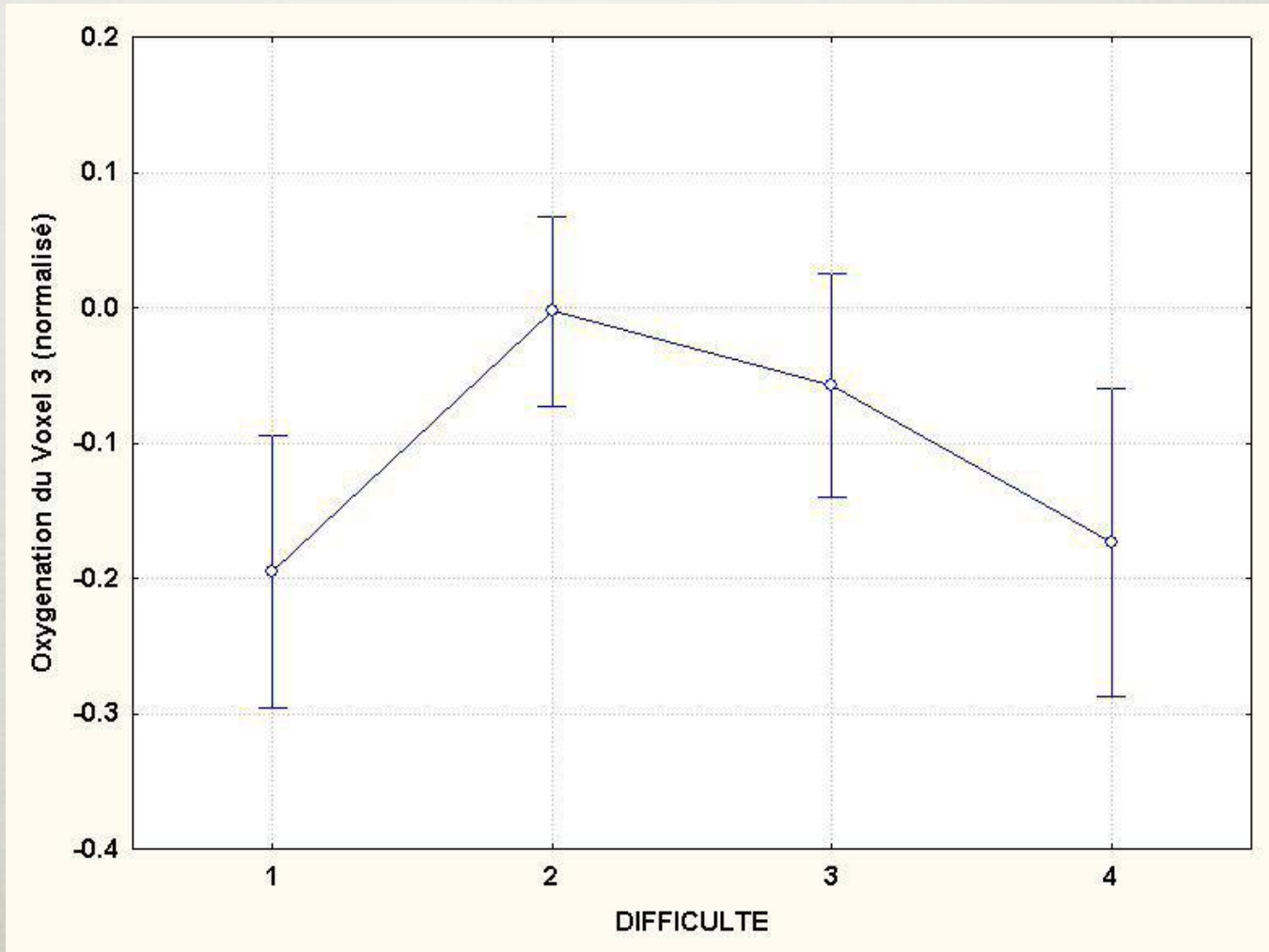
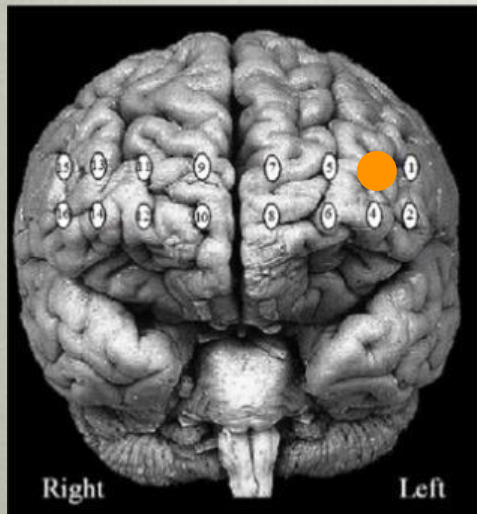
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# Mental workload and executive functioning: fNIRS results

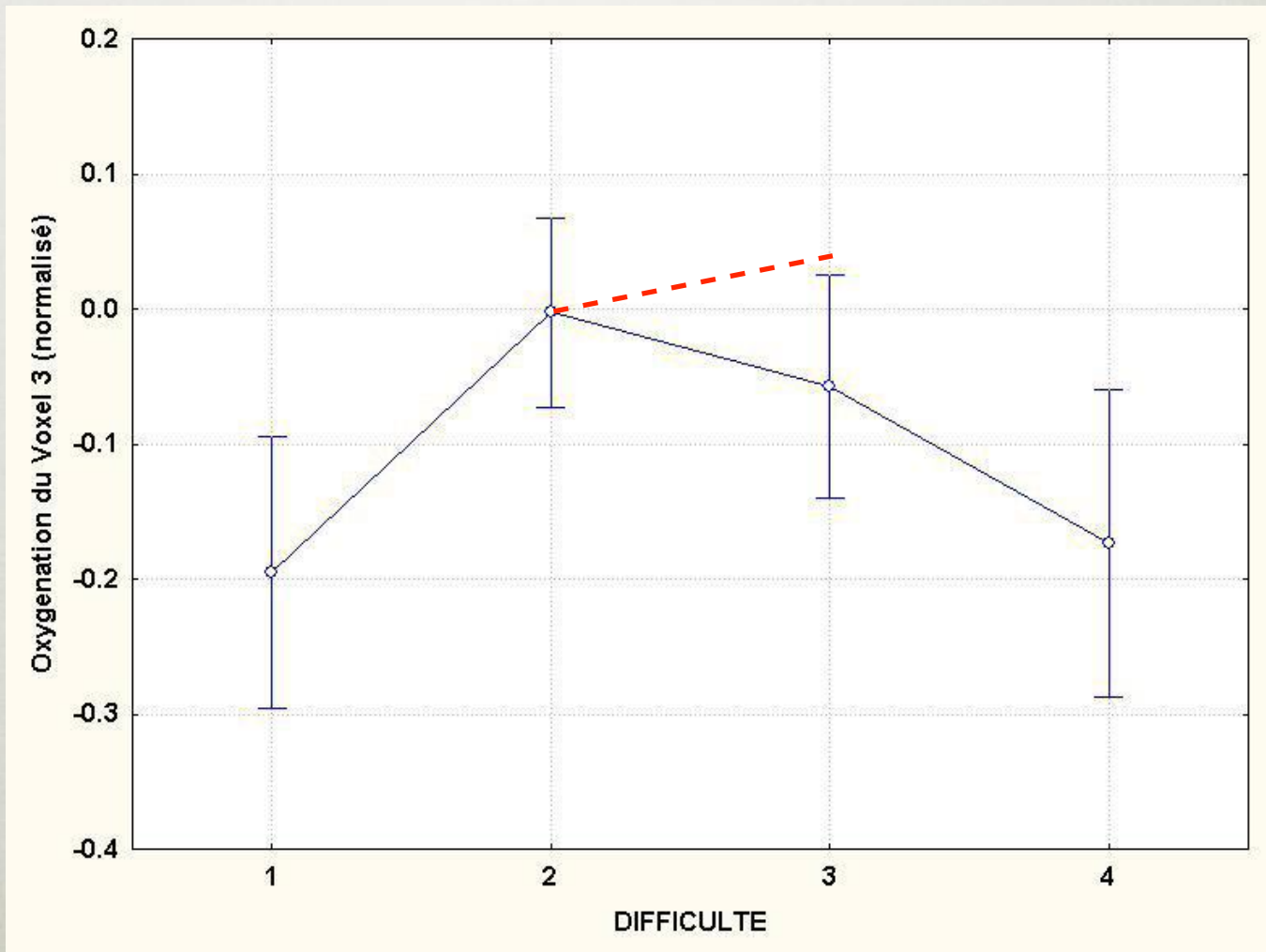
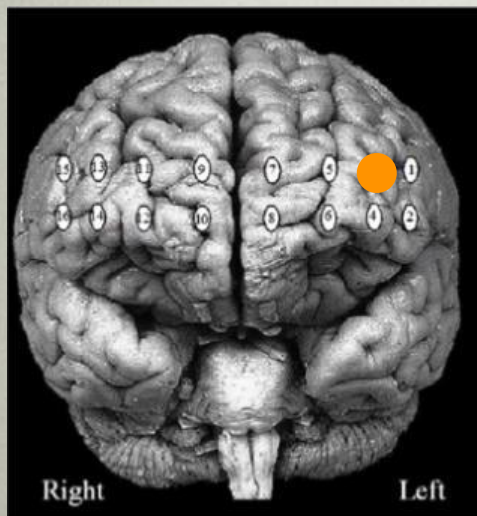
12 participants



$p=.045$

# Mental workload and executive functioning: fNIRS results

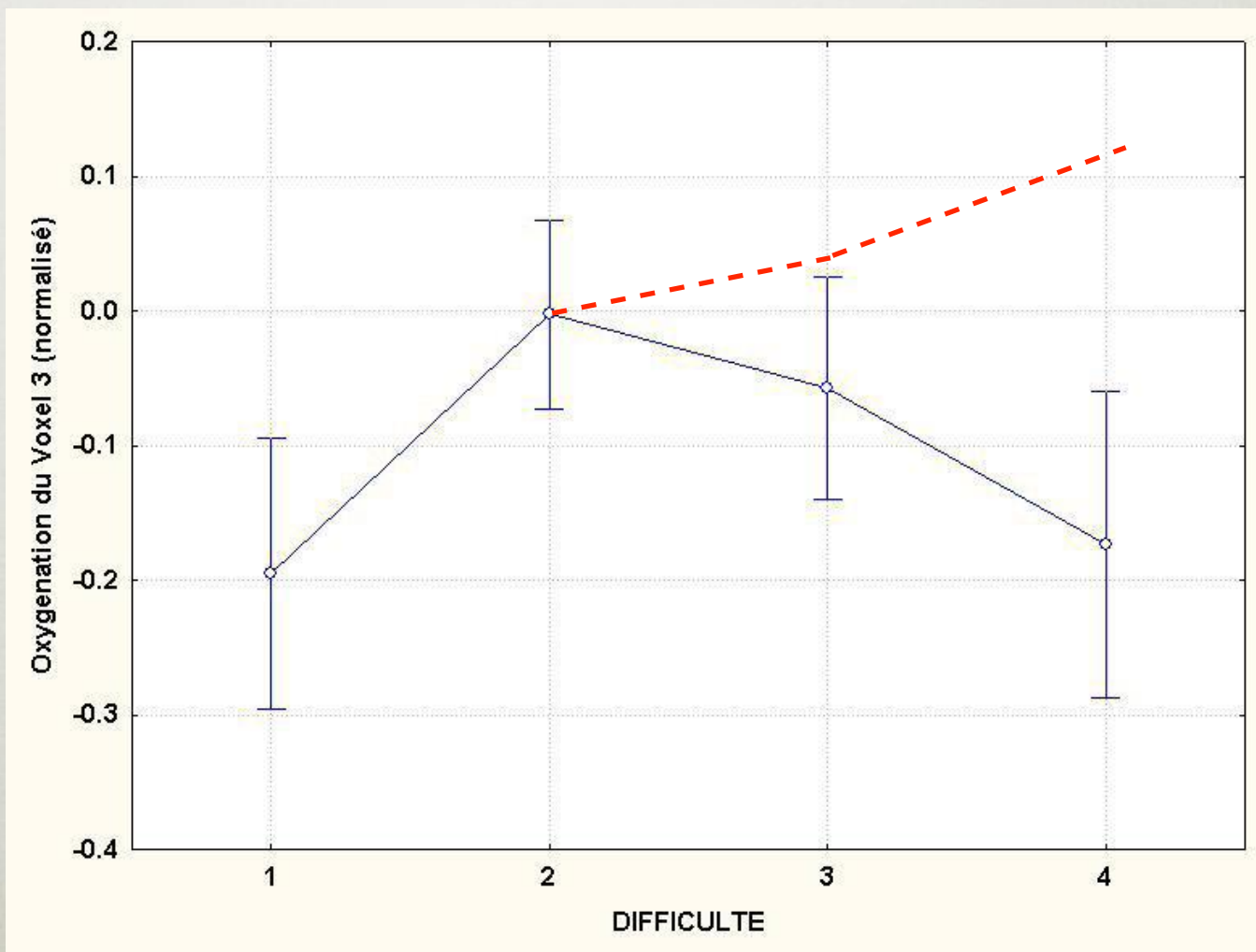
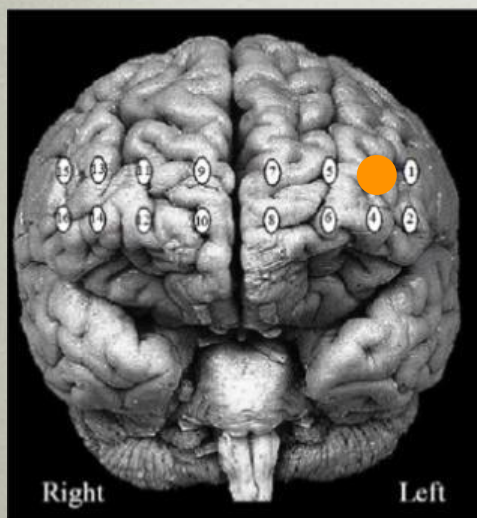
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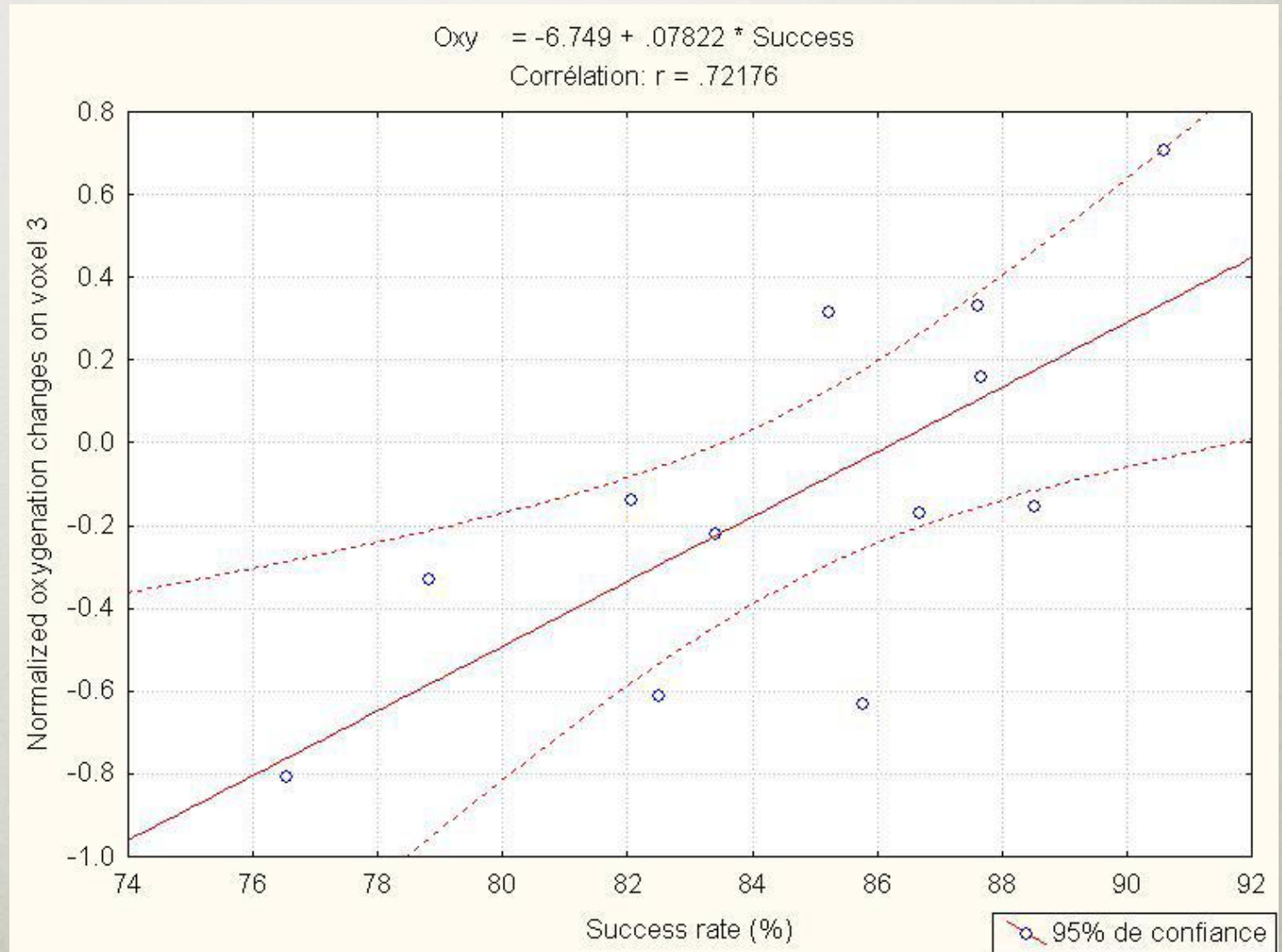
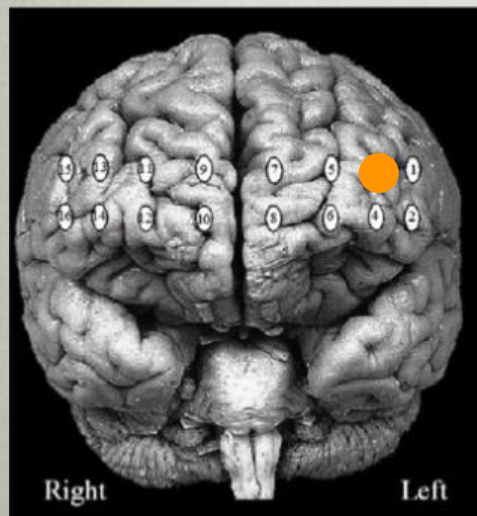
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# Mental workload and executive functioning: fNIRS results

12 participants



$p = .045$

**Inattentional deafness**

# **“Inattentional deafness” in aeronautics**



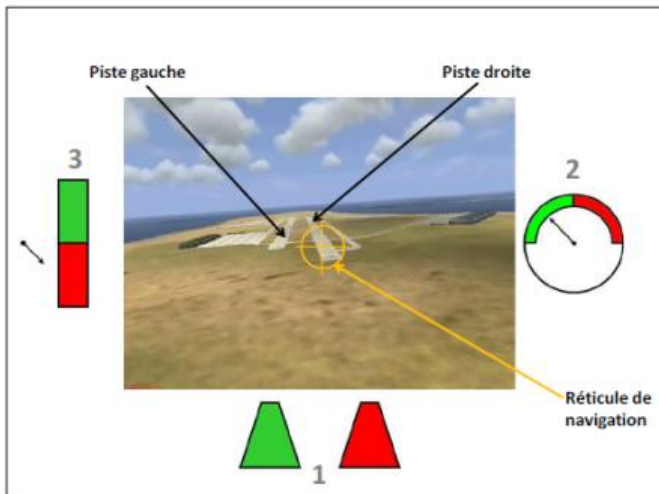
# Inattentional deafness

- ❁ “Cry wolf” effect leads the pilots to mistrust the alarms (Shapiro, 1994; Song & Kuchar, 2001; Sorkin, 1988)
- ❁ aggressive, distracting, and disturbing nature of auditory alarms (Doll, Folds, & Leiker, 1984; Edworthy et al., 1991, Peryer, et al. 2005).
- ❁ vision is dominant over hearing (Colavita et al., 79, Sinnett et al. 2007, ...) especially under high visual load (Mc Donald et Lavie, 2011)

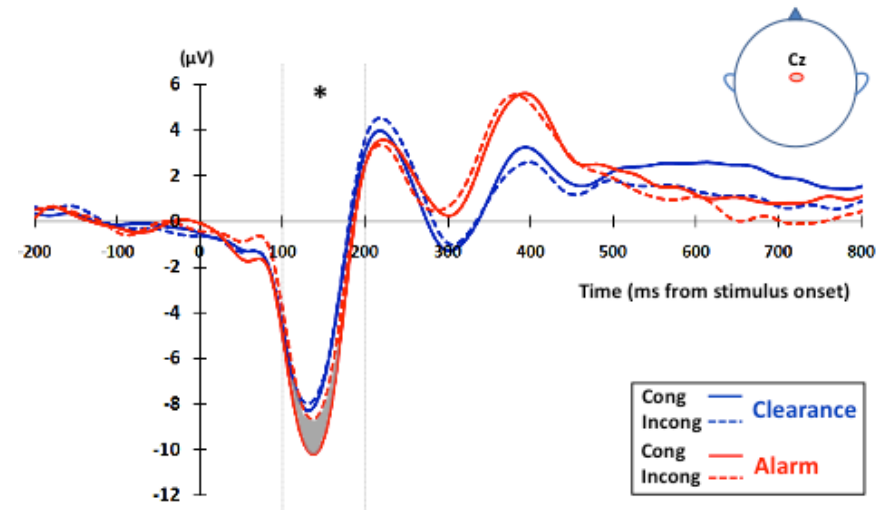
↳ *Inattentional deafness*

- ❁ Brain imagery studies reveals that visual processing may attenuate auditory processing (Lebib et al., 2003, Kramer et al., 1995) via direct visuo-auditory connections (see Macaluso et al., 2005)

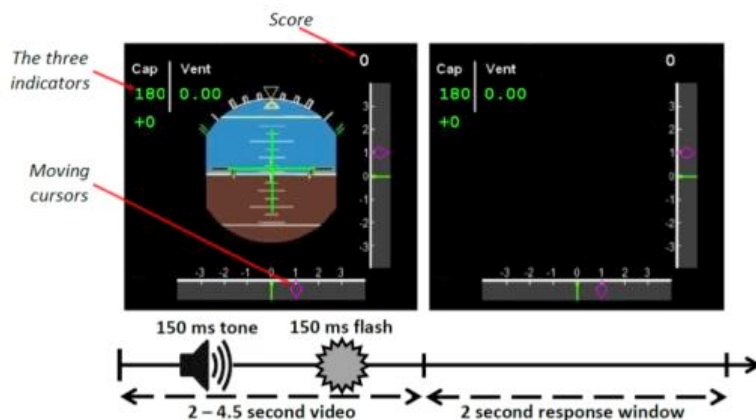




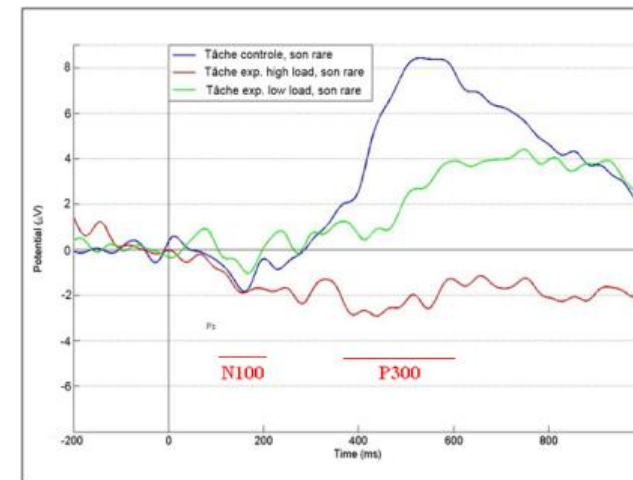
Audiovisual  
conflict/N100



Scannella, S., Cause, M., Chauveau, N., Pastor, J. Dehais, F. et al. (2013). Effects of the audiovisual conflict on auditory early process. *International Journal of Psychophysiology*



Visual load/P300



Giraudet, L., St Louis, M.E., Scannella, S., Cause, M. et al. (in Revision). P300 as an indicator of inattentional deafness. *Journal of Cognitive Neuroscience*

# Inattention deafness: flight simulator



## SCENARIO :

Landing gear failure: 900ft  
Triple Chime Alarm (86.3 dB)  
Windshear

14 participants (PPL) : 8 “deafness” vs 6 “alarm”  
 $\chi^2(1) = 7.02, p = .008, \Phi = .708$  (35 times more chance to perform go around if the auditory alert is perceived)

# Inattention deafness : ecological conditions



**Cognitive  
countermeasure**

# Design of cognitive countermeasures

- ☀ Paradox: *How can one “cure” human operators when they face inattentive blindness/deafness, if the alarms/systems designed to warn them are neglected?*
- ☀ Selective attentional processes [Posner and Dehaene, 94]
  - ☀ *Alerting* network: sustained attention
  - ☀ *Executive control* network: planning and decision making
  - ☀ *Orienting* network: disengaging, shifting and reengaging

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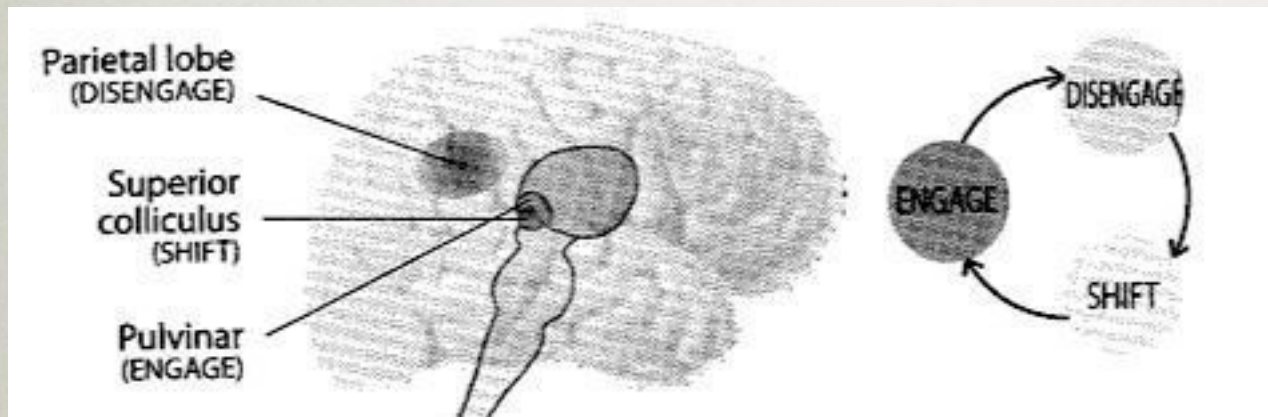
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☀ *Executive control* network: planning and decision making

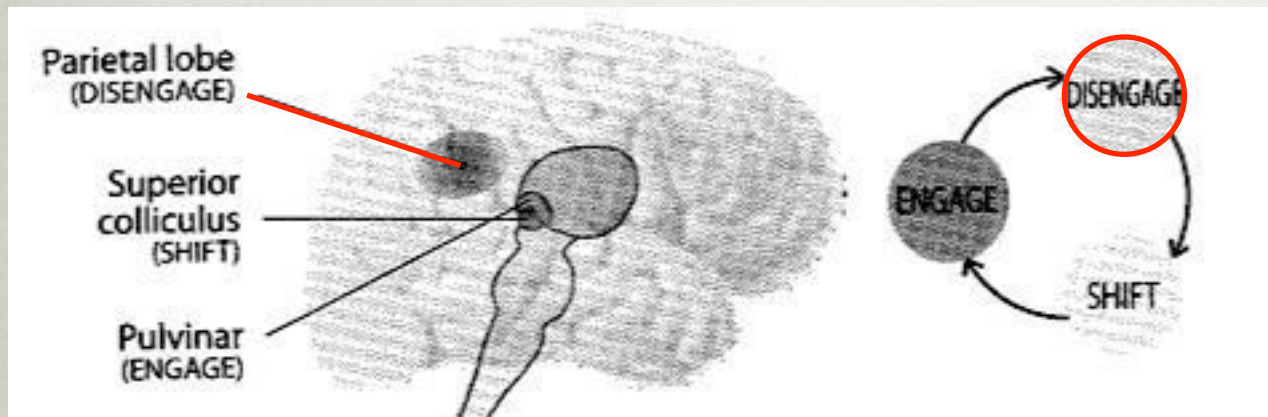
☀ *Orienting* network: disengaging, shifting and reengaging

Stressors and emotion affects orienting network [Pecher et al; 10]

# Perseveration/attentional impairment



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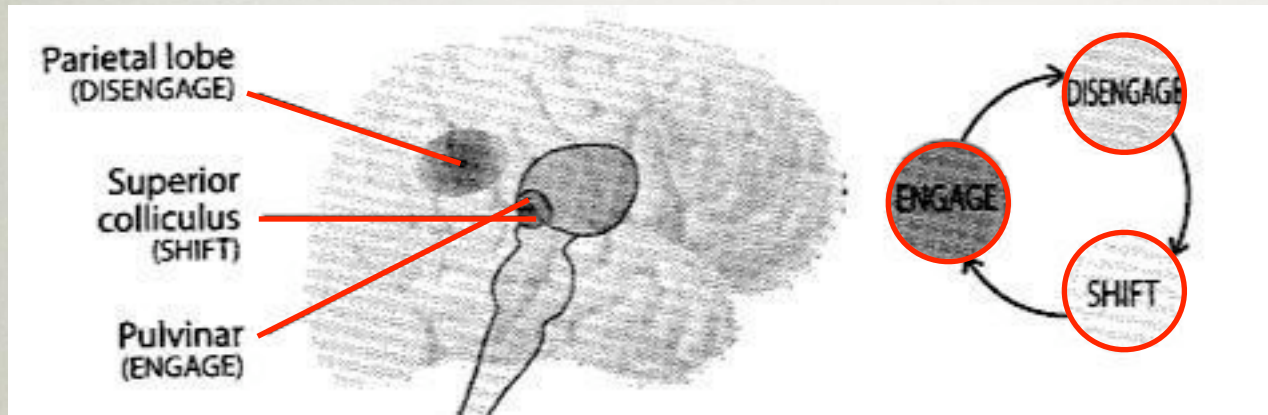




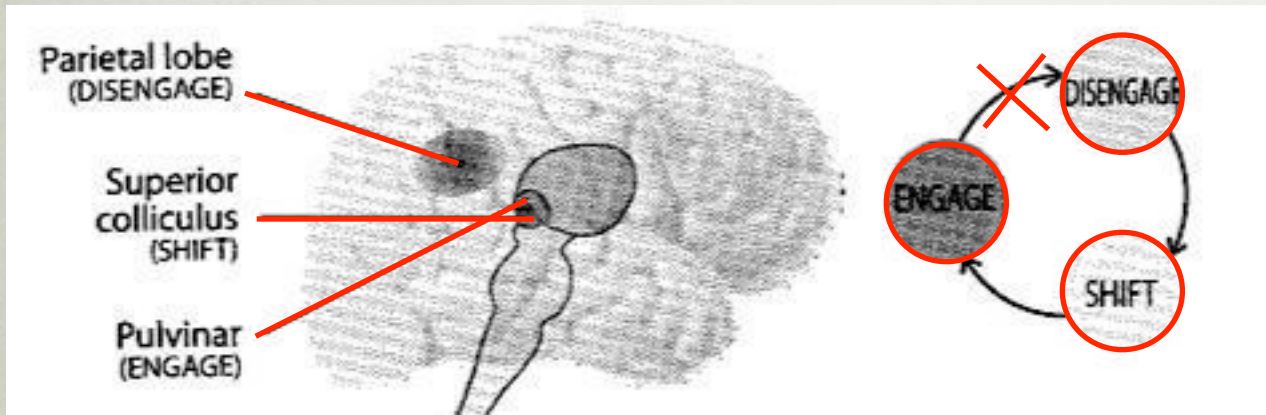
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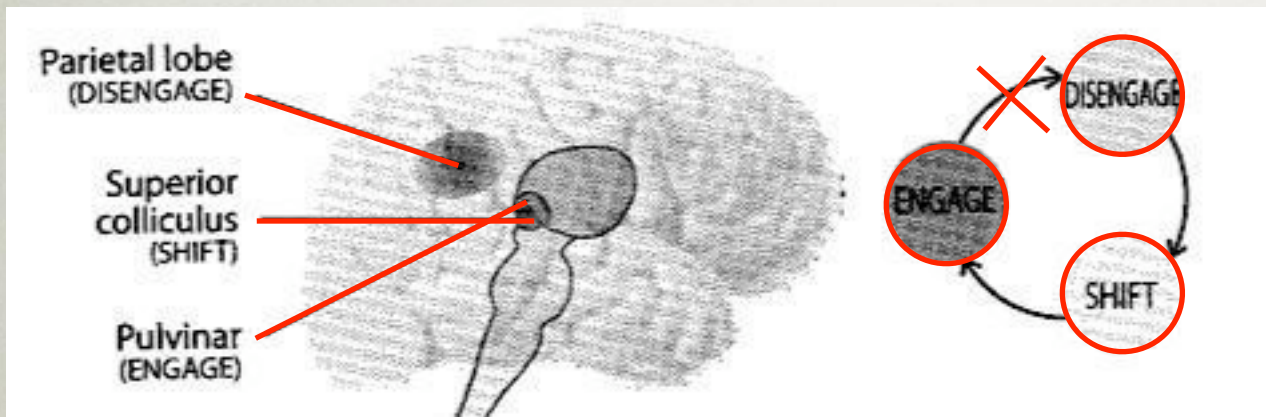
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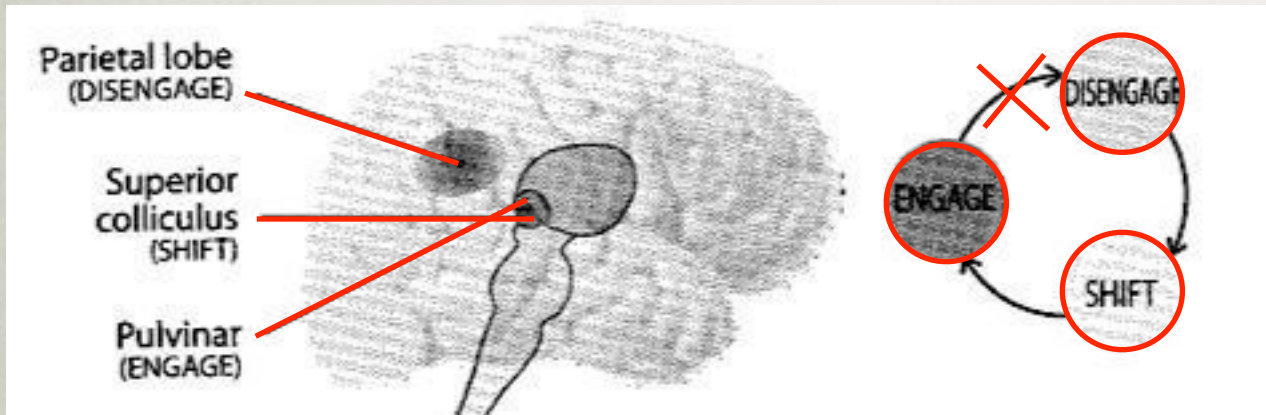


# Perseveration/attentional impairment



Inability to disengage attentional focus (Pulvinar) : patients (LaBerge, Carter, & Brown, 1992), “stressed” subjects (Tracy, Mohamed, Faro, Tiver, Pinus, & Bloomer, 2000).

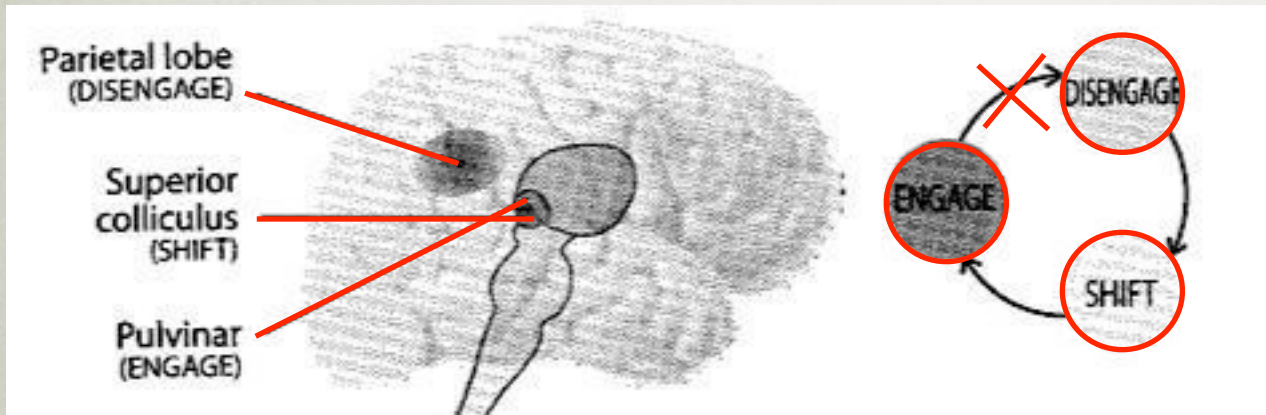
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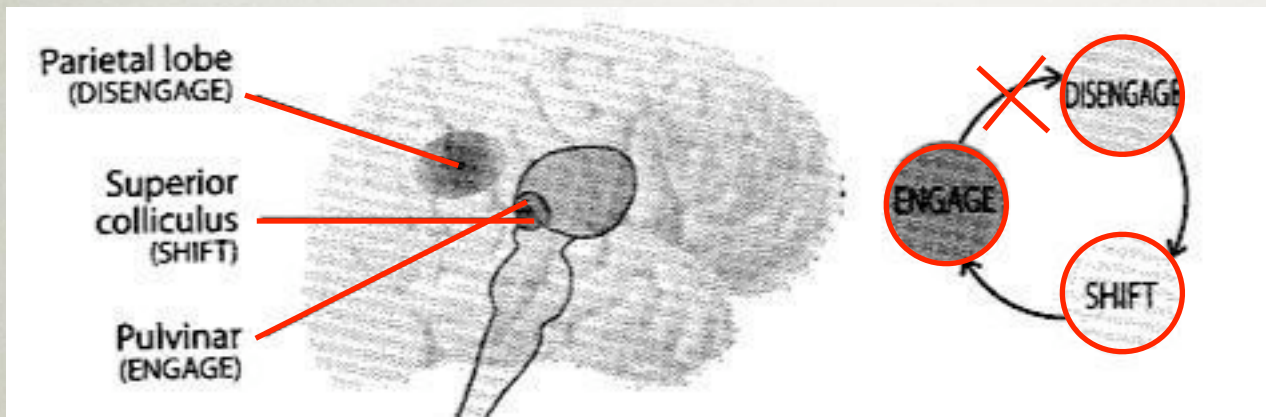


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☀ Remove the information/display on which the pilot is excessively focused

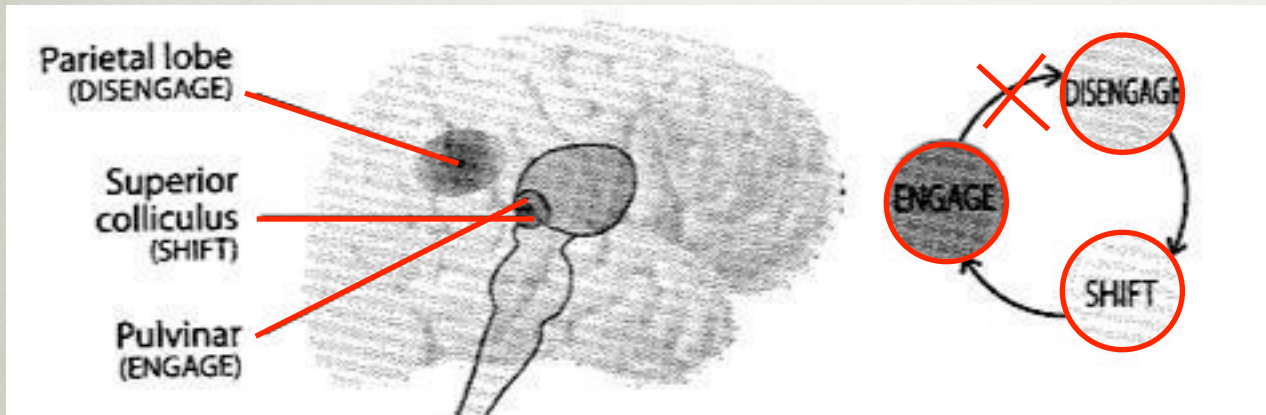
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  - ☀ Remove the information/display on which the pilot is excessively focused
  - ☀ Replace it with an accurate warning message

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“The GUI disengages / shifts the pilot’s attentional focus”

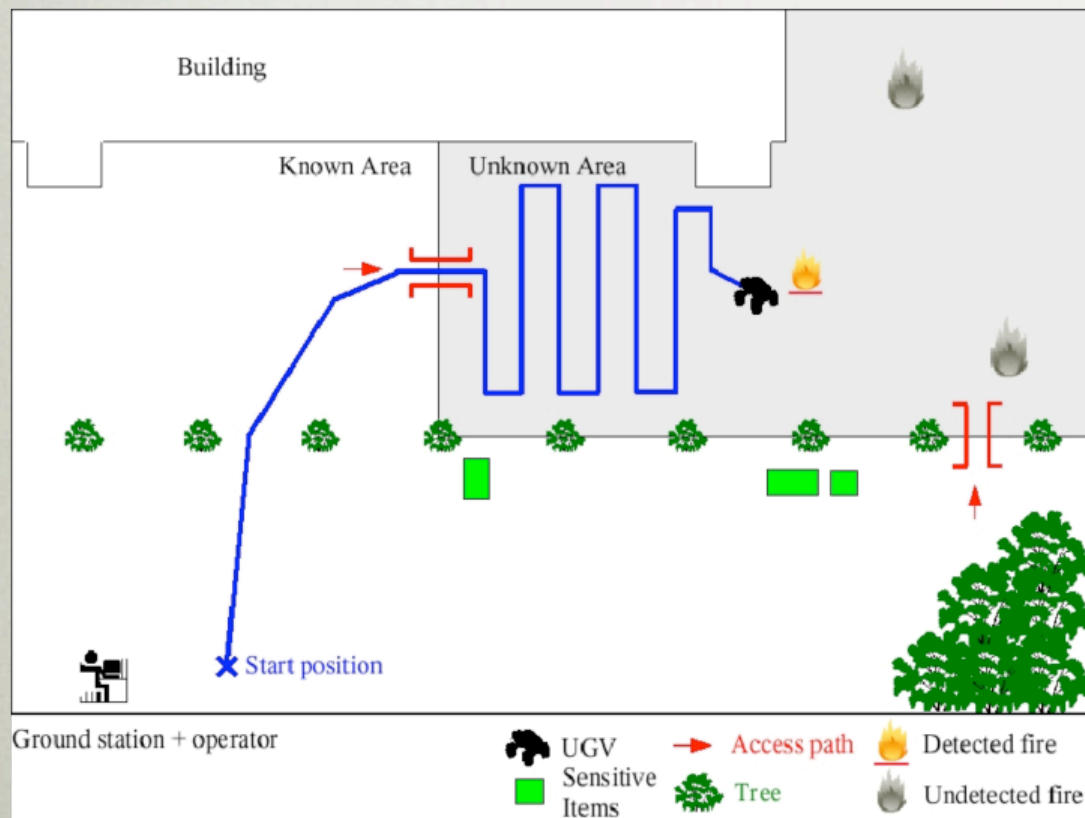


# MAIA project (2007-2014)



DGA fundings : “modelling cognitive conflicts in human operator / unmmaned vehicles interactions ”

Objective : developpment of an experimental set-up to study, detect and solve authority sharing conflicts



- ☼ Autonomous vehicles
- ☼ Generic embedded decisional architecture
- ☼ Concepts and tools for facilitating mutual situation awareness
- ☼ Scenarios and experimentalion

# The user's GUI

The GUI is divided into several functional areas:

- Top Left:** Configuration panel for 'Serveur Base' and 'Serveur Pilot', including IP addresses and port numbers. It also features a joystick control interface with a 'Periode (ms)' slider and a 'JoyStick' input field.
- Top Center:** A large video feed showing a 360-degree panoramic view of an outdoor area with a building and a field.
- Top Right:** 'Serveur Decouplé' configuration section with a 'Connecter' button, and a 'Données Payload' field.
- Middle:** A horizontal navigation bar with buttons: 'Planification', 'Reach Area', 'Search Target' (highlighted in green), 'Action on target', 'Back to Base', and 'Base'.
- Bottom Left:** A map view showing a target area outlined in red with 'EO' markers. It includes 'Start Time' and 'Mission' controls.
- Bottom Center:** A 'Manual' dialog box with the text 'A target has been detected. Take manual control to identify it' and 'Yes'/'No' buttons.
- Bottom Right:** 'Etat Vehicule' section showing two 'USG' sensors and a 'Niveau de Batterie' (battery level) indicator.
- Bottom:** A status bar with 'Debug' logs, 'Axis' (X, Y, Z) controls, 'Données Etat' (Status Data) input, and a 'pendre/call' button.

# The user's GUI

## Panoramic video

The screenshot displays a complex user interface for a drone control system. At the top center is a large panoramic video feed showing a wide-angle view of an outdoor area with a building and a field. Below the video is a navigation menu with buttons: Planification, Reach Area, Search Target (highlighted in green), Action on target, Back to Base, and Base. To the right of the menu are status indicators for GPS (a green square with 'GPS' text) and Batterie (a battery icon with 'Niveau de Batterie' text). Below the menu is a 'Manual' dialog box with the text 'A target has been detected. Take manual control to identify it' and 'Yes'/'No' buttons. The bottom section contains various control panels, including a 'Start Time' field, a 'Mission' panel with a satellite map, and several 'Pushbutton' controls for 'Axis X', 'Axis Y', and 'Axis Z'. There are also fields for 'Droptail Call' and 'Niveau de Batterie'.

# The user's GUI

Panoramic video

The screenshot displays a complex user interface for a drone control system. At the top center, a panoramic video feed shows a wide-angle view of a grassy field with a large building in the background. Below this, a horizontal menu contains several options: "Planification", "Reach Area", "Search Target", "Action on target", "Back to Base", and "Base". The "Search Target" option is highlighted in green. To the right of the menu, there are two green triangular icons labeled "USG" and a battery icon labeled "Niveau de Batterie". Below the menu, a large white box displays the word "Manual" in bold black text. To the left of the "Manual" box, there is a small satellite map showing a red rectangular area with several green markers. Below the map, a message box contains the text: "A target has been detected. Take manual control to identify it". At the bottom of the interface, there are several input fields and buttons, including "Start Time", "Mission", "add Drone", "request IM", "request GPS", "Axis X", "Axis Y", "Axis Z", "Send request IM", "send", "sendCall", "start", "start 1", "start 2", and "runTime".

Synoptic

# The user's GUI

Panoramic video

Planification Reach Area Search Target Action on target Back to Base Base

Manual

A target has been detected. Take manual control to identify it

Yes No

Tact. Map

GPS

Niveau de Batterie

# The user's GUI

Panoramic video

Synoptic

Planification Reach Area Search Target Action on target Back to Base Base

Manual

Tact. Map

A target has been detected. Take manual control to identify it

Yes No

GPS

USG

Niveau de Batterie

Debug

Axis X, Y, Z

Send Control

# The user's GUI

Panoramic video

**Synoptic**

Planification Reach Area **Search Target** Action on target Back to Base Base

**Tact. Map**

**Manual**

A target has been detected. Take manual control to identify it

Yes No

**Mo de Procedures**

GPS

Niveau de Batterie

# The user's GUI

Panoramic video

The screenshot displays a complex user interface for a drone control system. At the top center is a panoramic video feed of a large building. Below it is a navigation menu with buttons: Planification, Reach Area, Search Target (highlighted in green), Action on target, Back to Base, and Base. To the right is a 'Health' panel showing two USG sensors, a battery level indicator, and a large green 'GPS' icon. On the left, a 'Tact. Map' shows an aerial view with a red target area. A 'Manual' dialog box is open, displaying the message 'A target has been detected. Take manual control to identify it' with 'Yes' and 'No' buttons. The bottom of the interface contains various control parameters and status indicators.

Synoptic

Planification Reach Area Search Target Action on target Back to Base Base

Manual

A target has been detected. Take manual control to identify it

Yes No

« Health »

Tact. Map

GPS



# The user's GUI

Panoramic video

Synoptic

Planification Reach Area Search Target Action on target Back to Base Base

Tact. Map

Manual

A target has been detected. Take manual control to identify it

Yes No

GPS

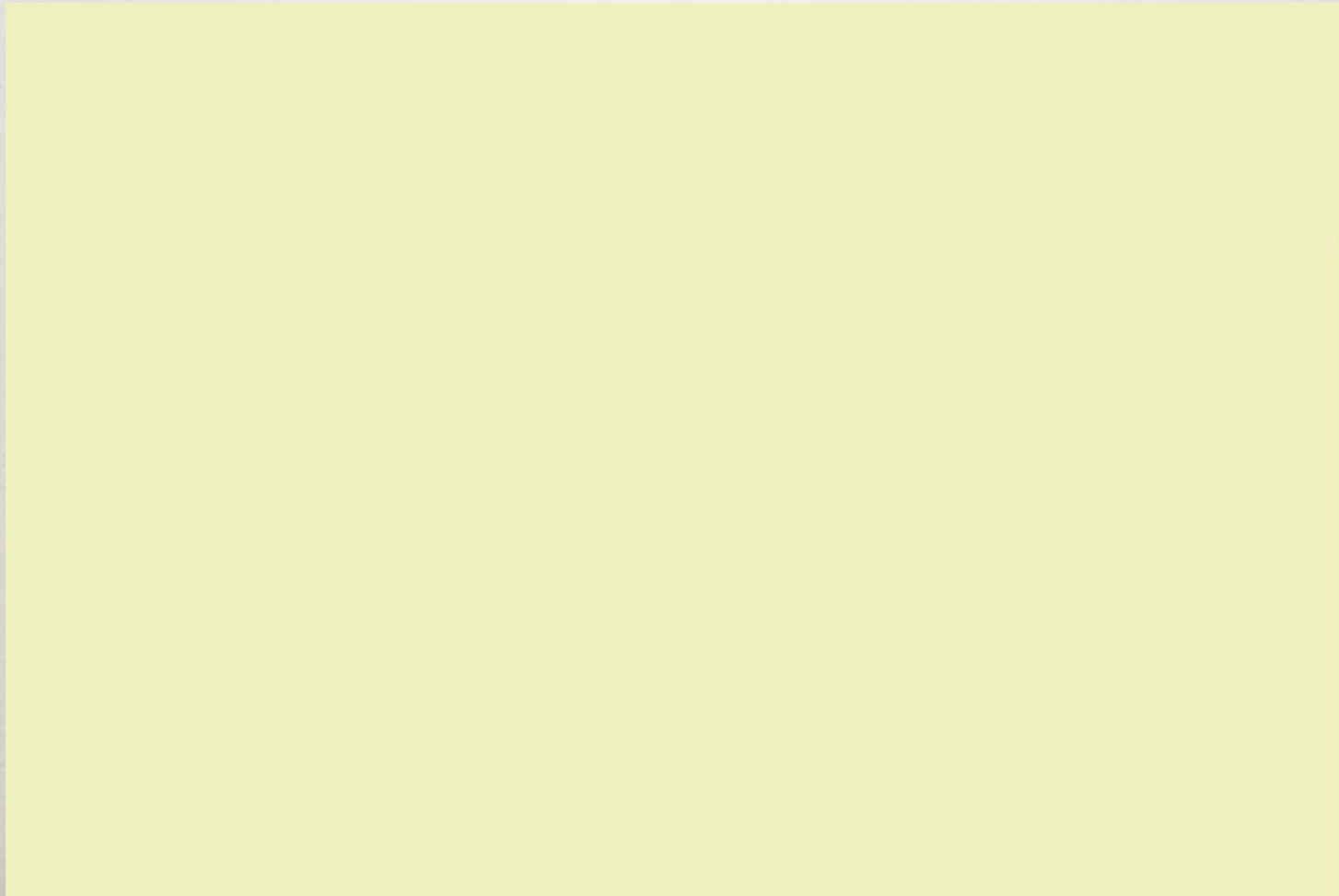
« Health »

Procedures

+ Wizard of Oz

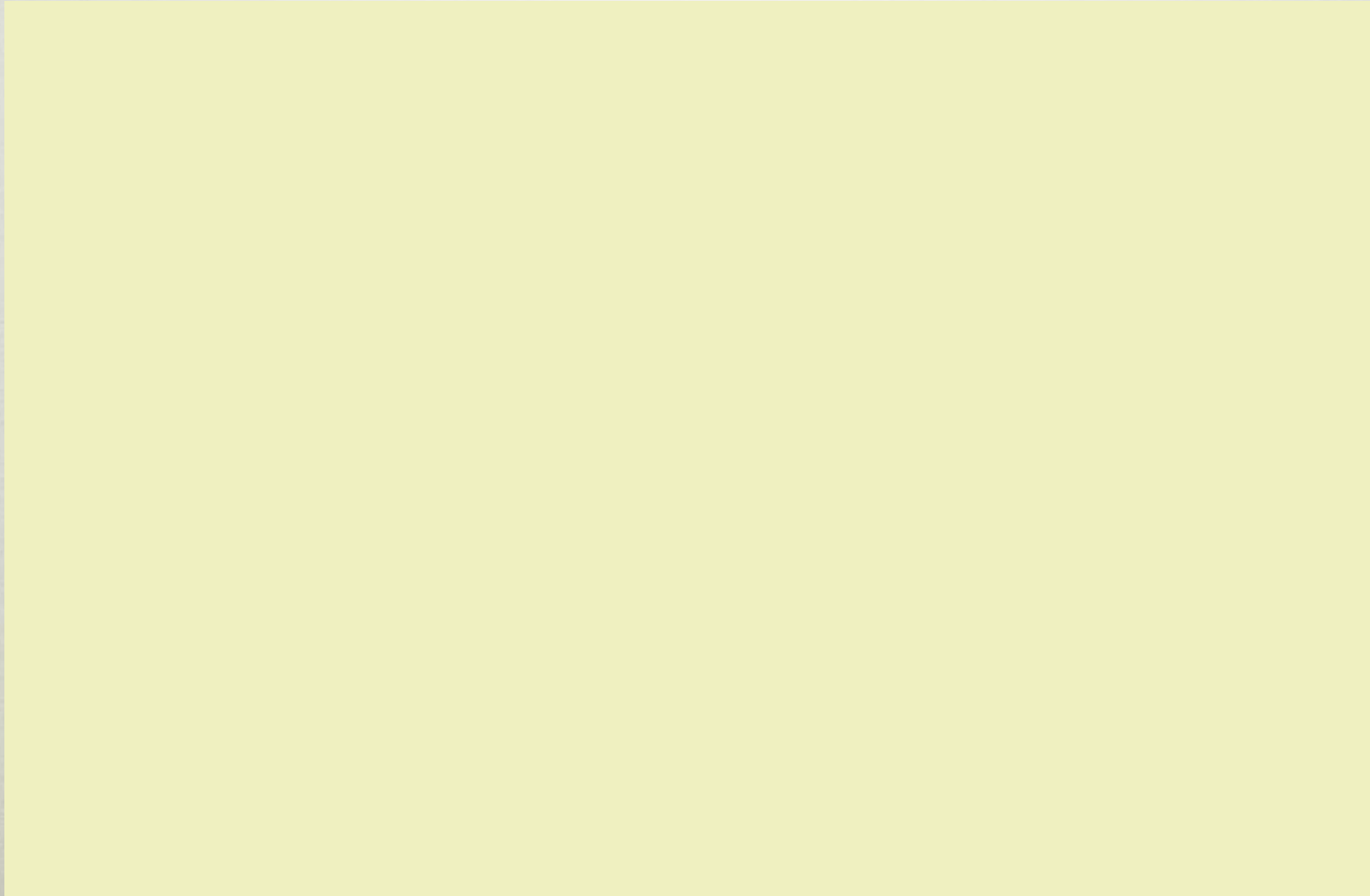
# **Groupe 1: No cognitive countermeasures**

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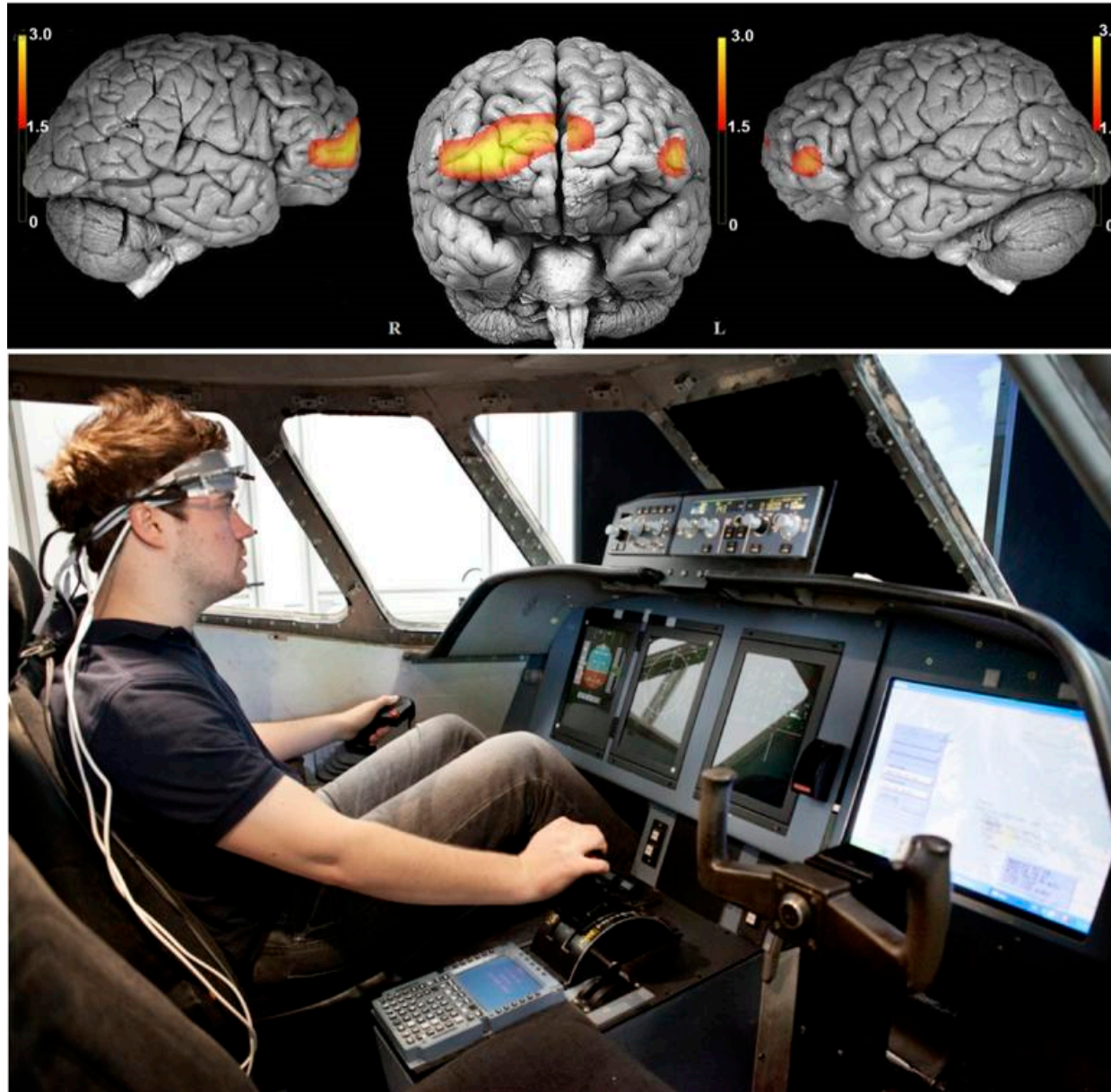


# **Groupe II : Cognitive countermeasures**

# Groupe II : Cognitive countermeasures



# **On-line Monitoring**



# Brain Computer Interface (BCI)

- ☀ Working Memory (WM) is a key executive function to operate aircraft [Causse et al., 11] especially during ATC Communication [Causse et al., 10; Taylor et al., 05]
- ☀ WM is fundamentally limited: design of a “passive” BCI dedicated to predict WM performance and to adapt interaction



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## “Ecological” Flying Task



# Brain Computer Interface (BCI)

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## “Ecological” Flying Task



*“Supaero32, speed 270 knots, heading 300 degrees, altitude 3000 feet, Over”*

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filtering

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filtering

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## “Ecological” Flying Task



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filtering

Machine Learning

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## “Ecological” Flying Task



“Supaero32, speed 270 knots, heading 300 degrees, altitude 3000 feet, *Over*”

filtering

If “error” then repetition of instructions

Machine Learning

# Brain Computer Interface (BCI)

- Working Memory (WM) is a key executive function to operate aircraft [Causse et al., 11] especially during ATC Communication [Causse et al., 10; Taylor et al., 05]
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## “Ecological” Flying Task

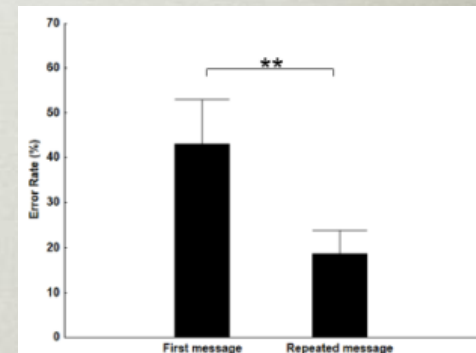


“Supaero32, speed 270 knots, heading 300 degrees, altitude 3000 feet, Over”

filtering

If “error” then repetition of instructions

Machine Learning



accuracy > 70%  
specificity = 80%

# **Neurocockpit project: eye movement**

## **Real-Time Detection of "Explore/Exploit" Extrema**

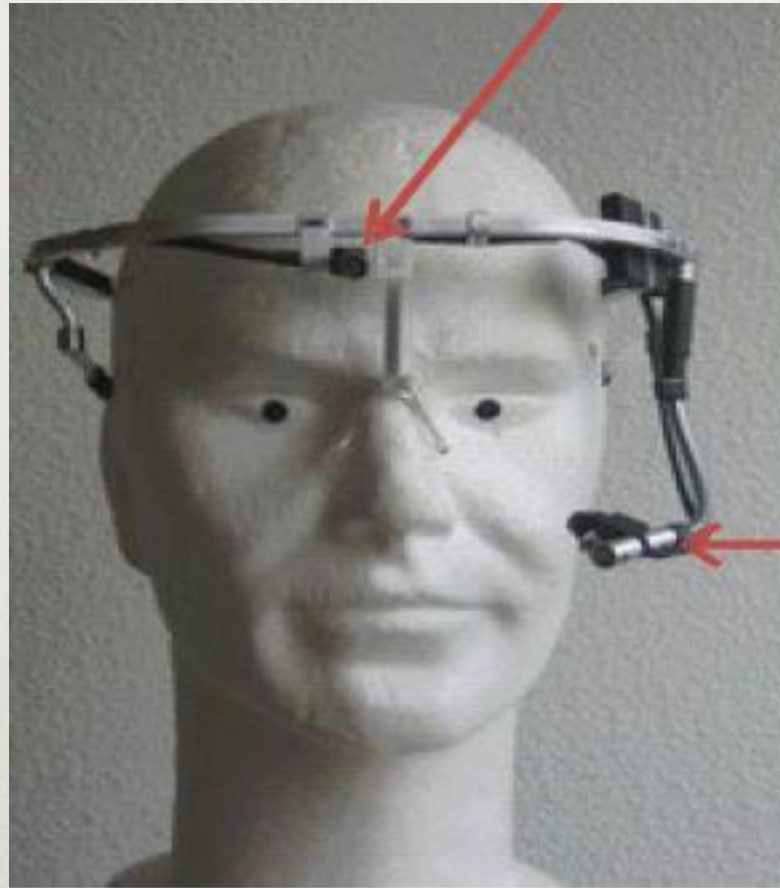
**Human Factors and  
Neuroergonomics Team**

**ISAE, Toulouse, 2013**



# Go Around Study: BEA/Air France/Airbus

Scene Camera



Eye camera

# Go Around Study: BEA/Air France/Airbus



2 synchronized eye trackers

# Eye metrics : BEA study

