What Neuroscience Can Tell Us about Human Error in Aviation

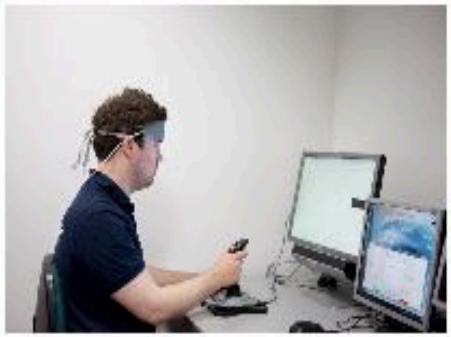
F. Dehais - dehais@isae.fr
Professor at ISAE
Human Factors and Neuroergonomics Lab


arte

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

Human Factors and Neuroergonomics

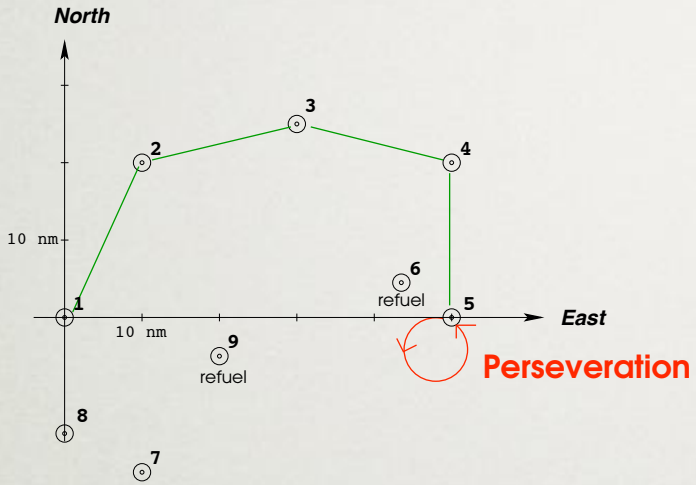
- **Since 2004, ISAE is developing an expertise in Neuroscience for Human Factors**

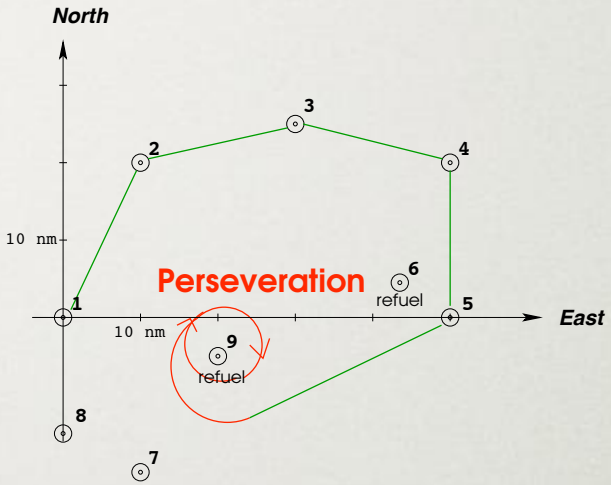
- **A pluridisciplinary team :**
  - 3 permanent members (1 Professor, 1 Associate Professor, 1 Research engineer)
  - 7 PhD students (Supaero, X)
  - 4 post-doctoral fellows and 2 associate researchers

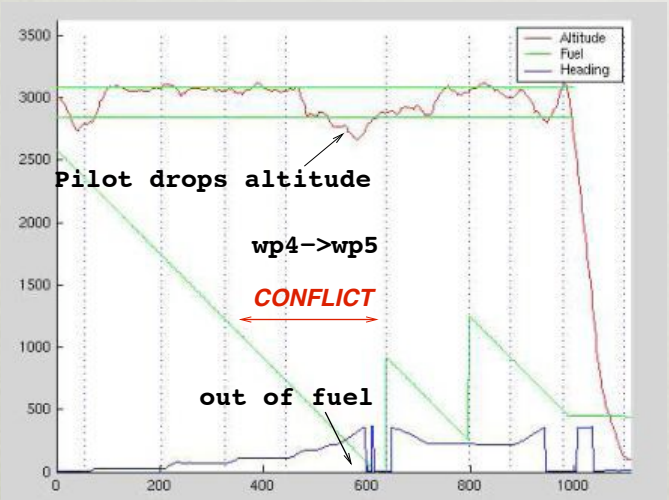
- **Expertise :** Neuroscience, Human Factors, Psychophysiology, Signal Processing & Algorithm, Experimentation

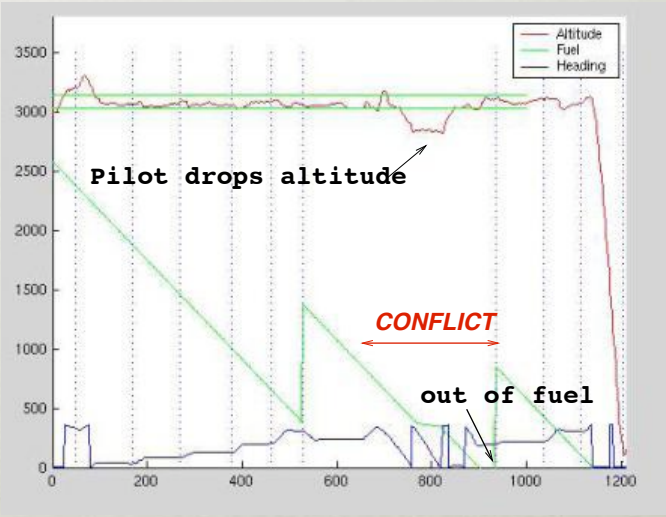
National Institute of Information and Communications Technology

Preamble



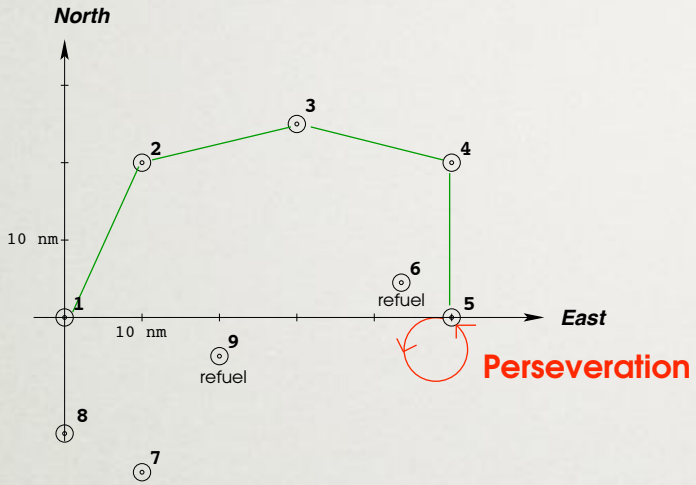


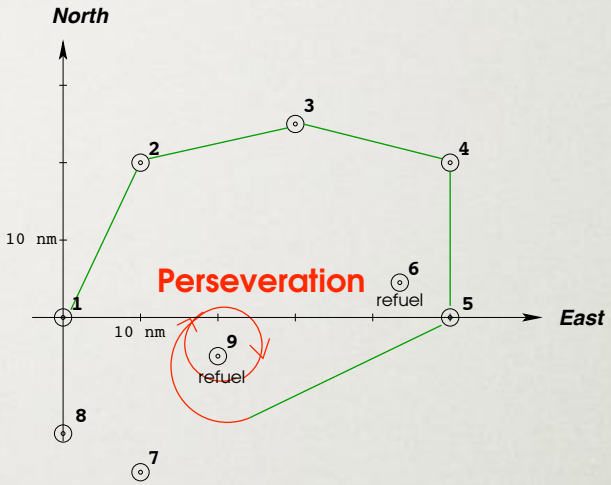


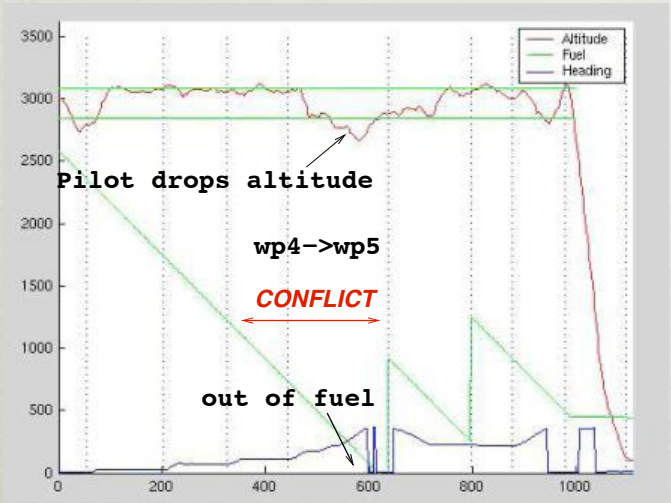


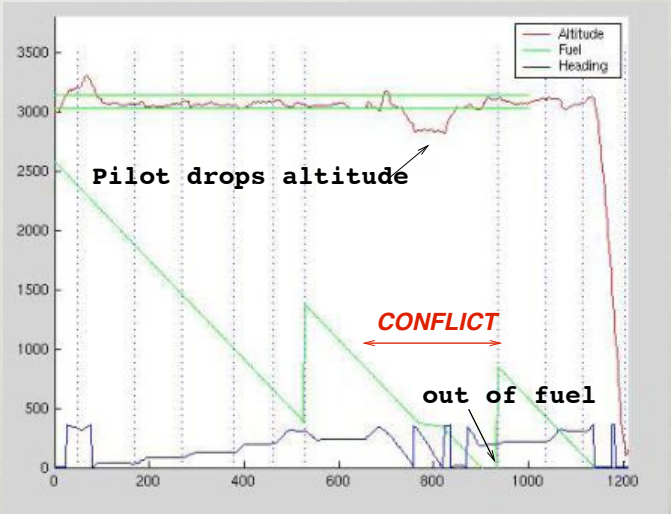
[Dehais et al., 03, 07, 09]

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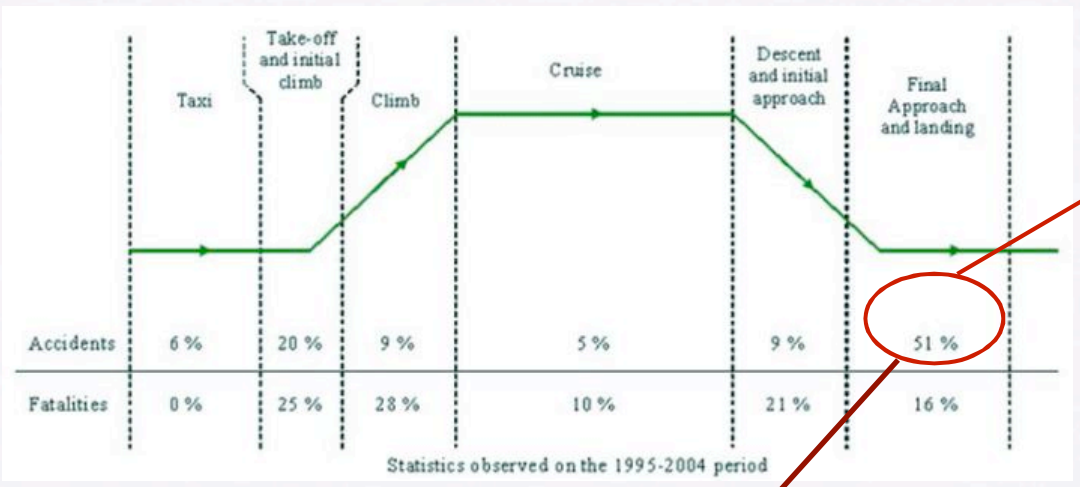
an inhibition impairment caused by irremediable loss of an associated neural network or a temporary loss of an executive function induced by stress and emotion [Simpson&al, 2001]

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
  - incertainty & complexity
  - a defeat...

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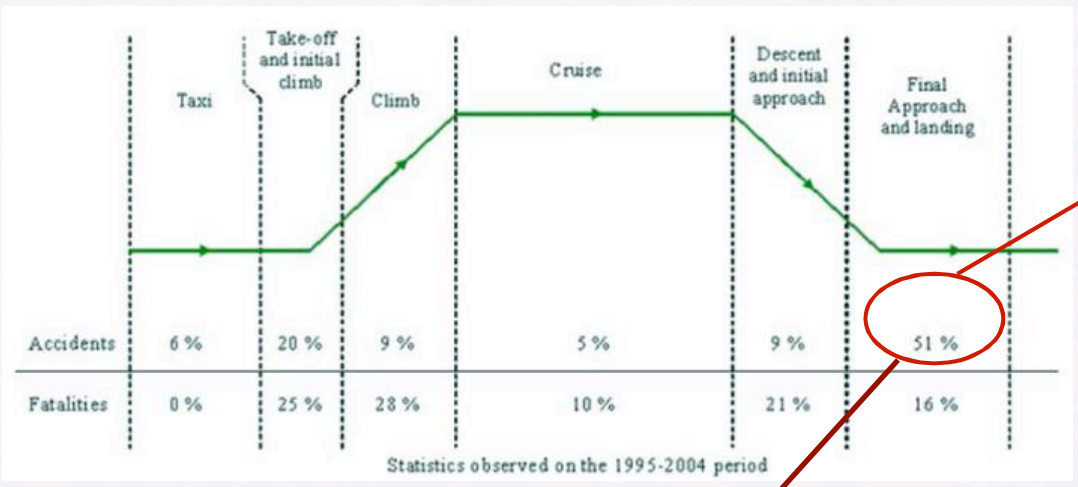

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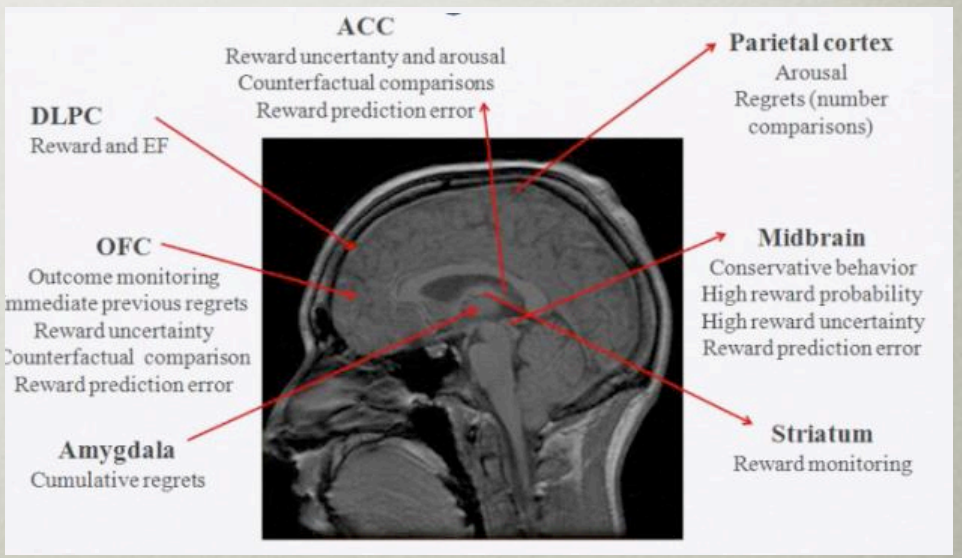


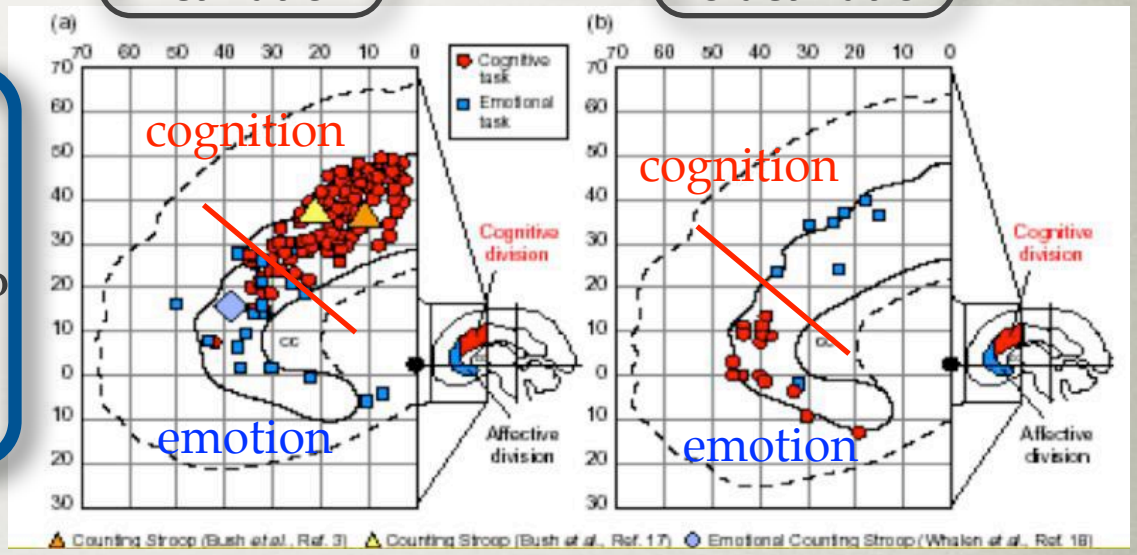
Emotion and decision making :

The cognition/emotion "shift" hypothesis

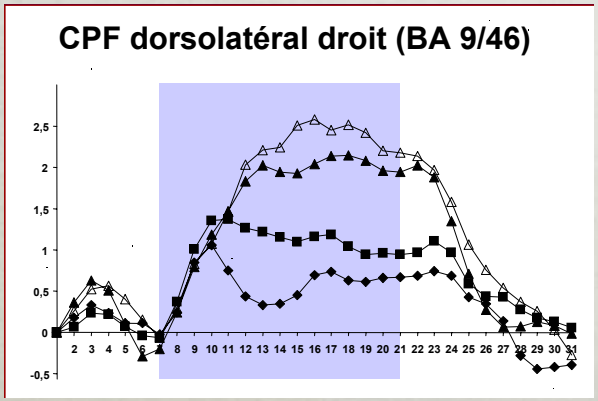
- **G. Bush & al, 00 :** cognitive stroop task- "2 2 2"
- **Whalen & al, 98 :** "emotional stroop task - "murderer murderer murderer"

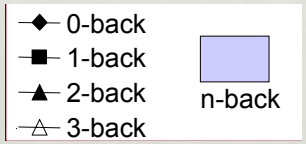
Activation

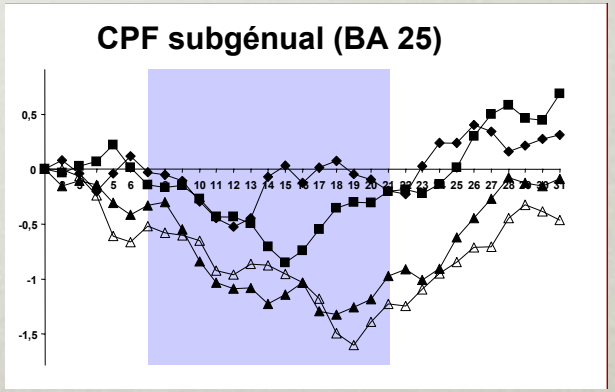
De-activation



Anterior Cingular Cortex (ACC)







Pochon et al 2002 : effects of motivation on cognition

"Cold" vs. **"Hot"**

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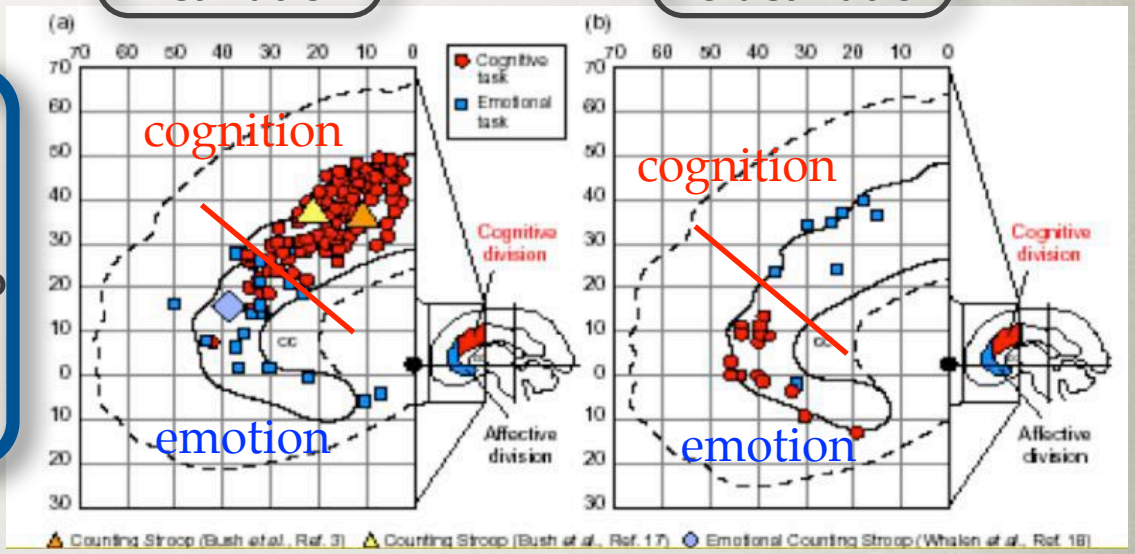

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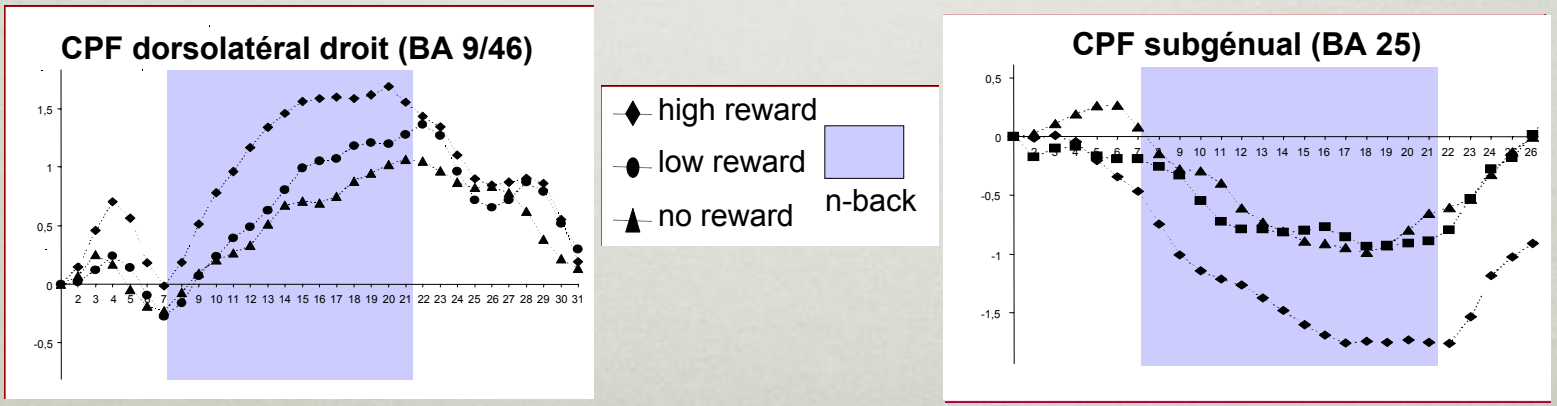

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Emotion and decision making

(PhD thesis - M. Causse 2006-2009)

Aeronautical situation

Laboratory

Rational decision making under uncertainty and incentive conditions

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

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→ Analysis of the brain networks involved during "the shift"

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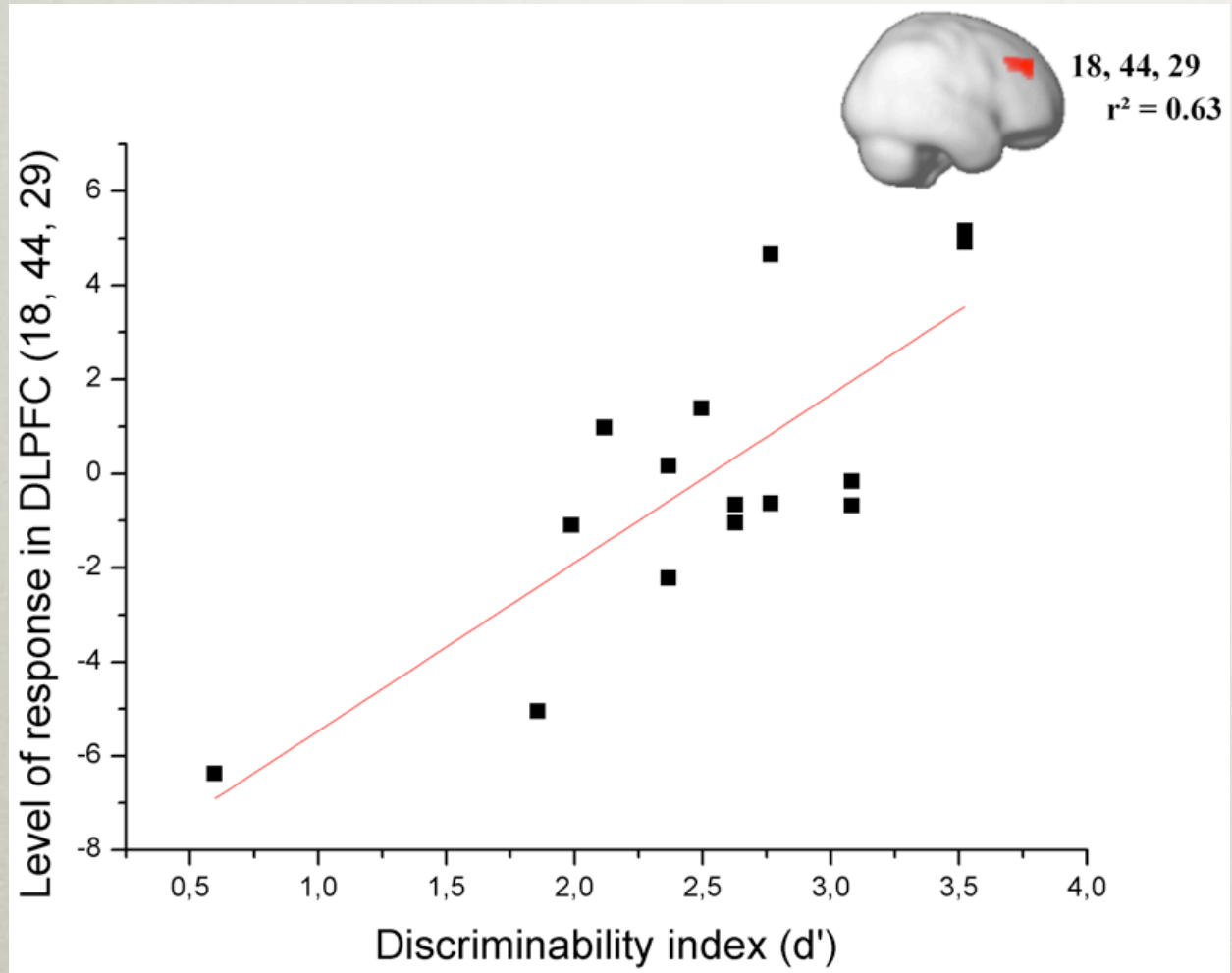

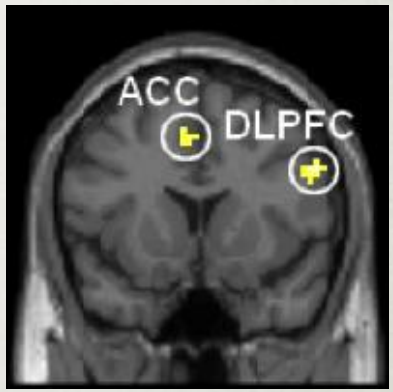

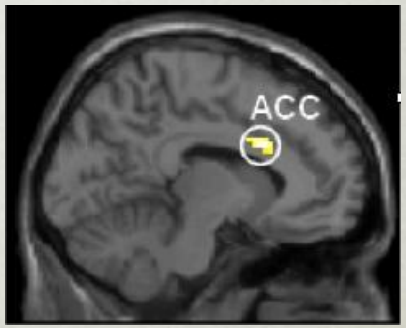

[Causse et al, Neuroimage, 2013]

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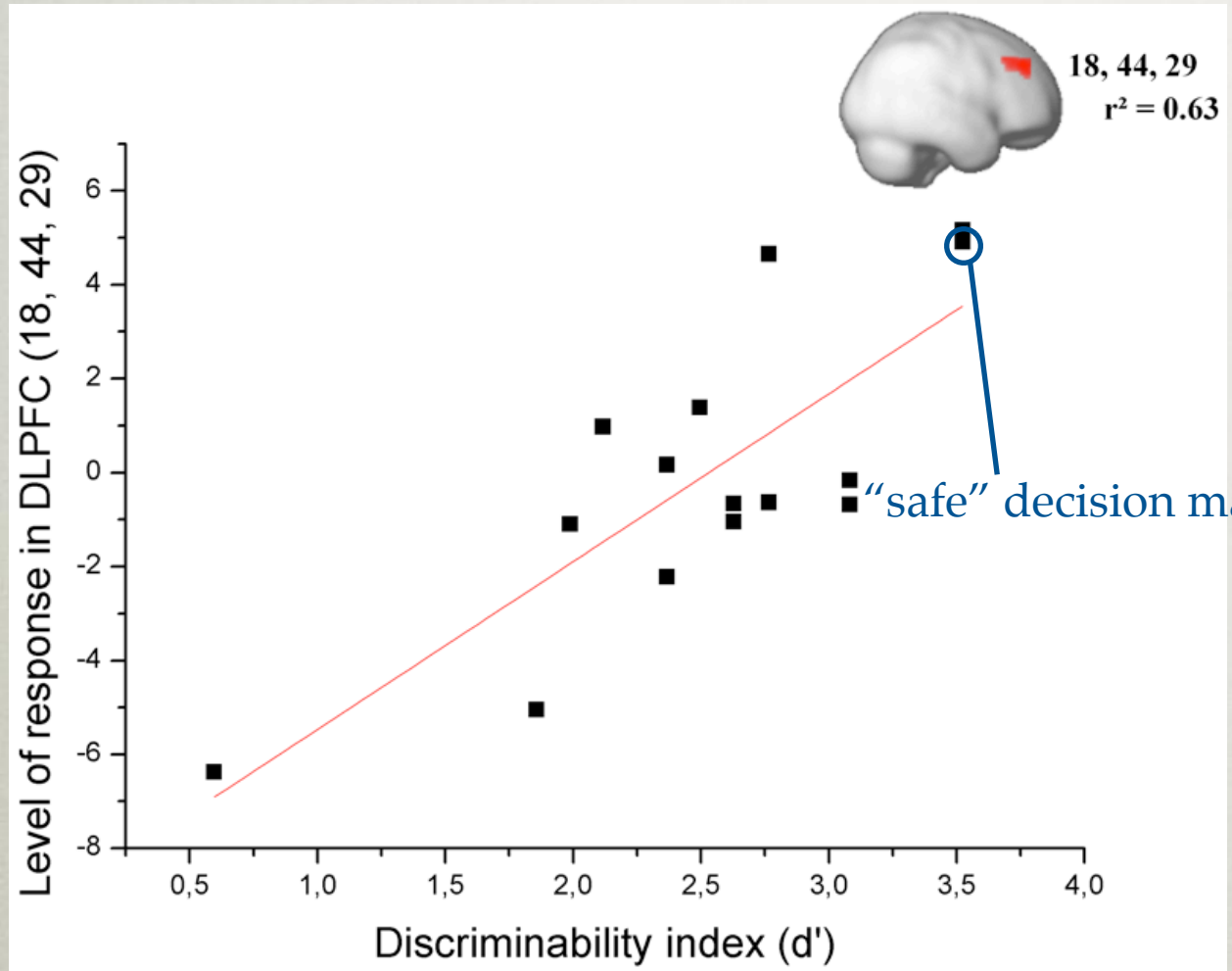
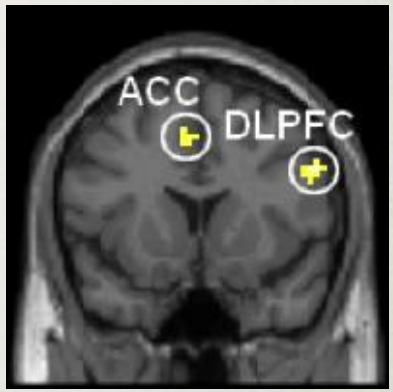
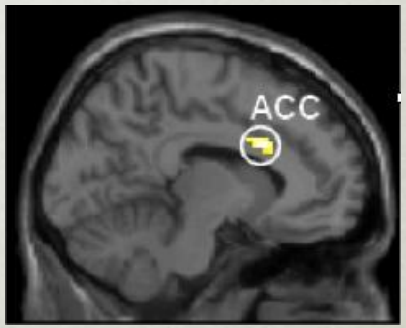


"safe" decision maker





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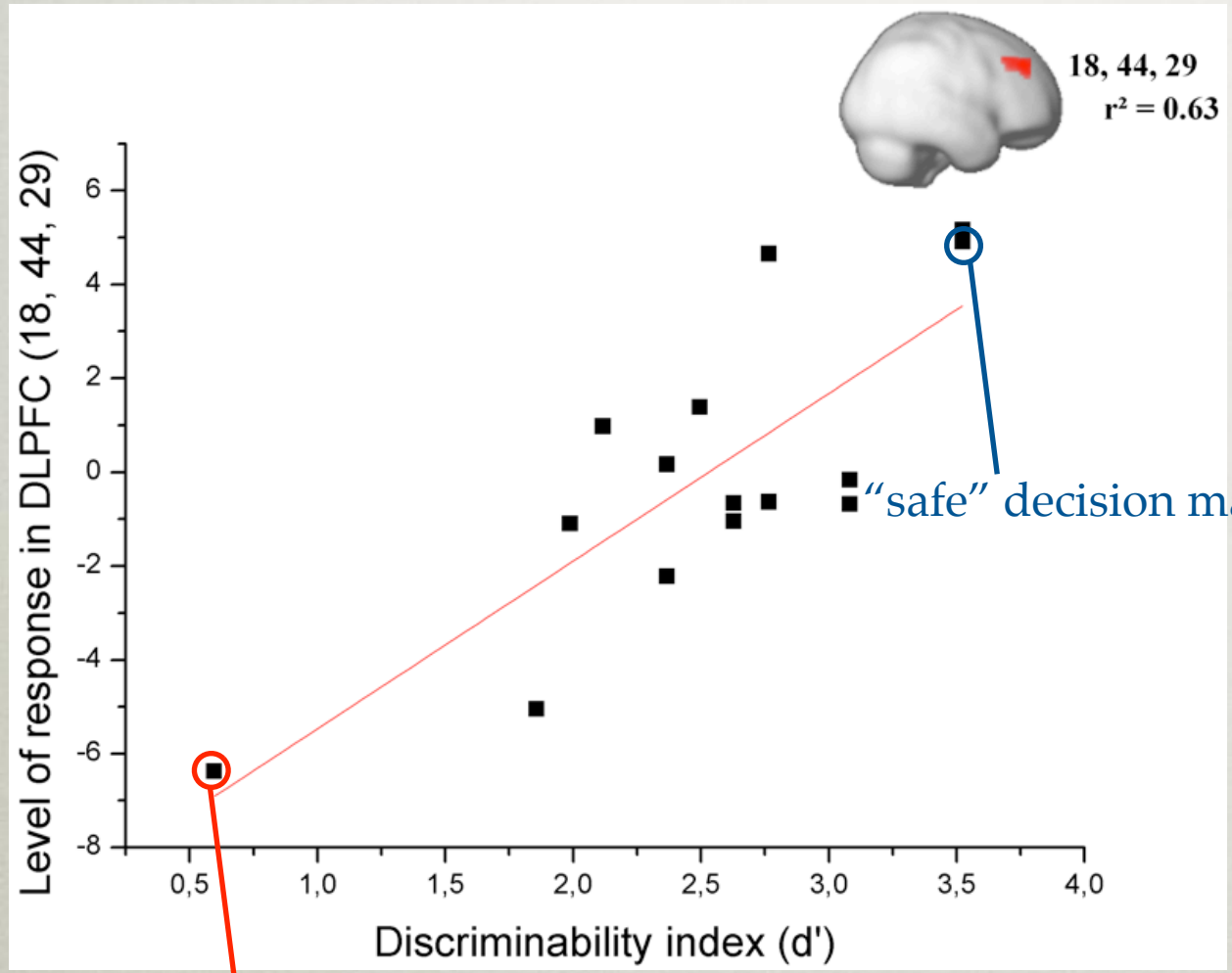
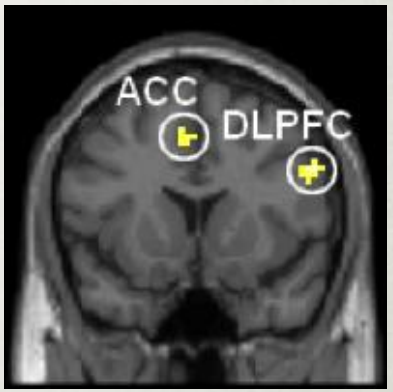
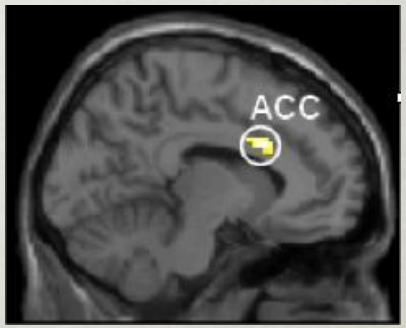


"safe" decision maker

"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

Phd thesis G. Durantin (2012)

- 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 ($Hb0_2$ converts to HHb)
    - correlated with fMRI measurements [Cui et al, 2011]
  - good spatial resolution compared to EEG (1 cm^2)
  - slow optical signal: poor temporal resolution - hemodynamic response

Mental workload and executive functioning

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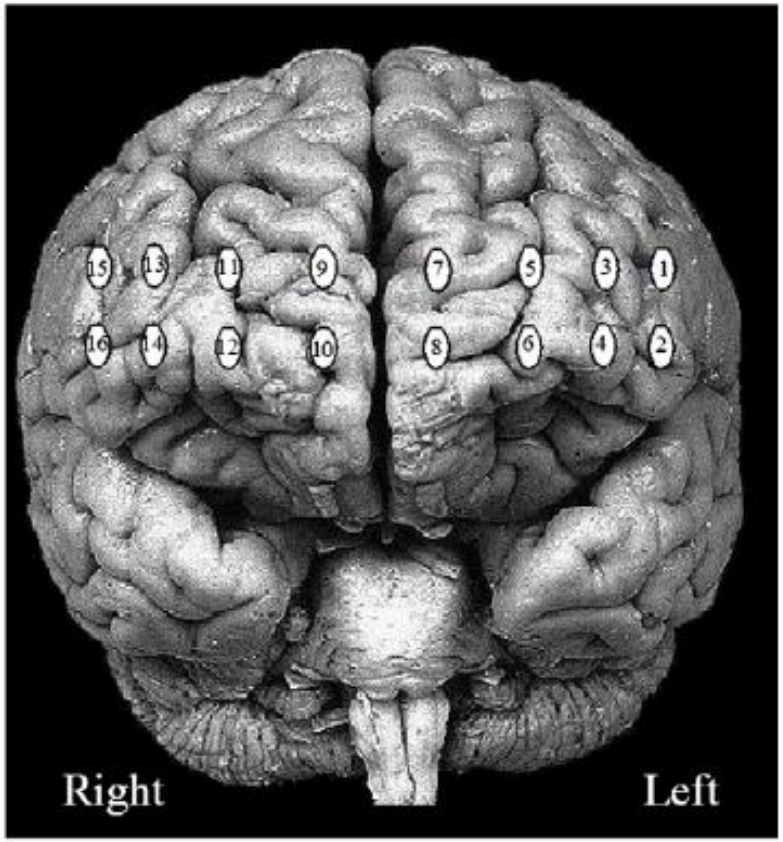

Measurement of **blood concentrations** → **oxygenated** hemoglobin

Measurement of **blood concentrations** → **deoxygenated** hemoglobin

Mental workload and executive functioning

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Increased oxygenation with neuronal activity

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

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- UAV: sustained attention [Menda et al., 11]
- ATC: task difficulty (# of planes)[Ayaz et al., 11]

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- ATC: task difficulty (# of planes)[Ayaz et al., 11]
- ATC: processing load [Ayaz et al., 11]

Mental workload and executive functionning

Phd thesis G. Durantin (2012)

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

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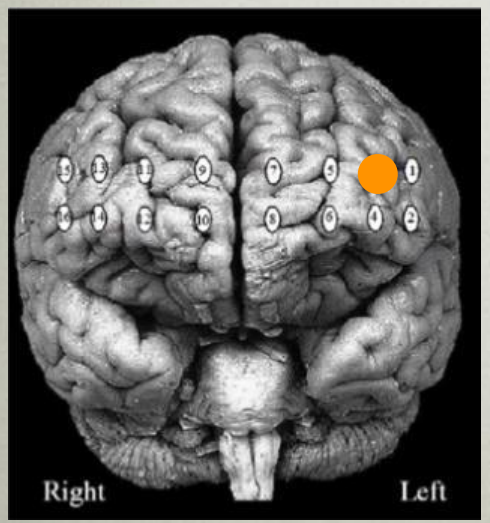
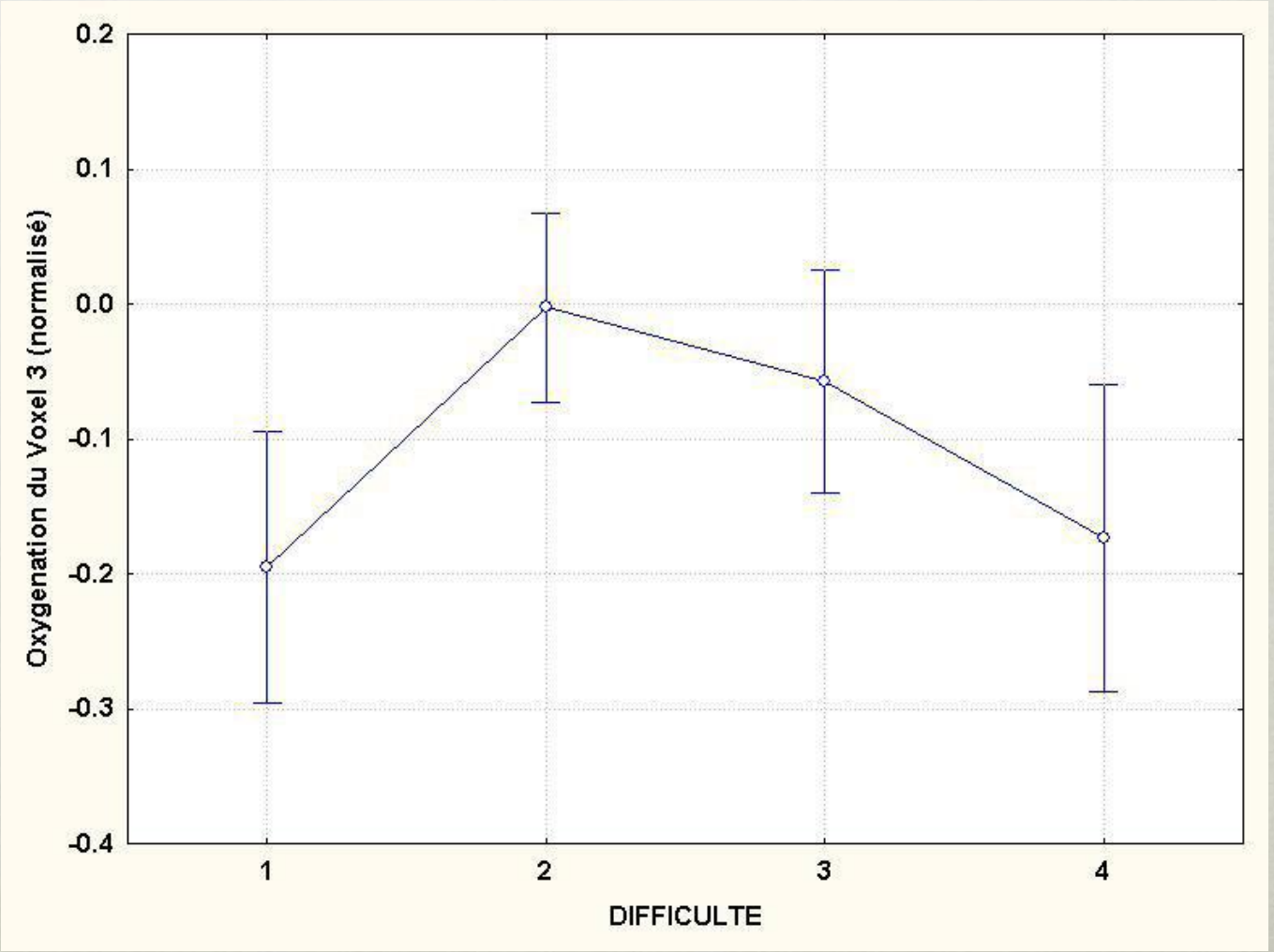
Mental workload and executive functioning: fNIRS results

12 participants





p=.045

[Durantin et al., Behavioral Brain Research, in Press]

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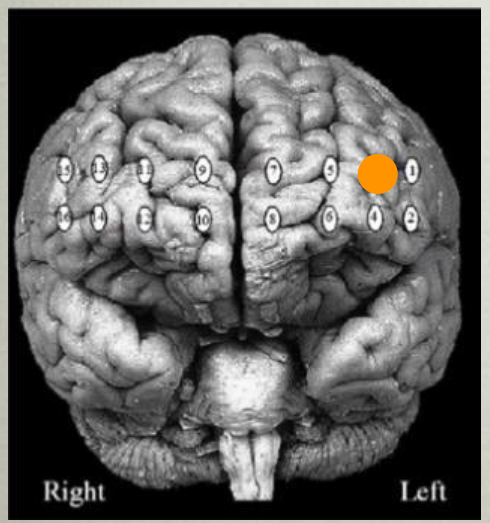

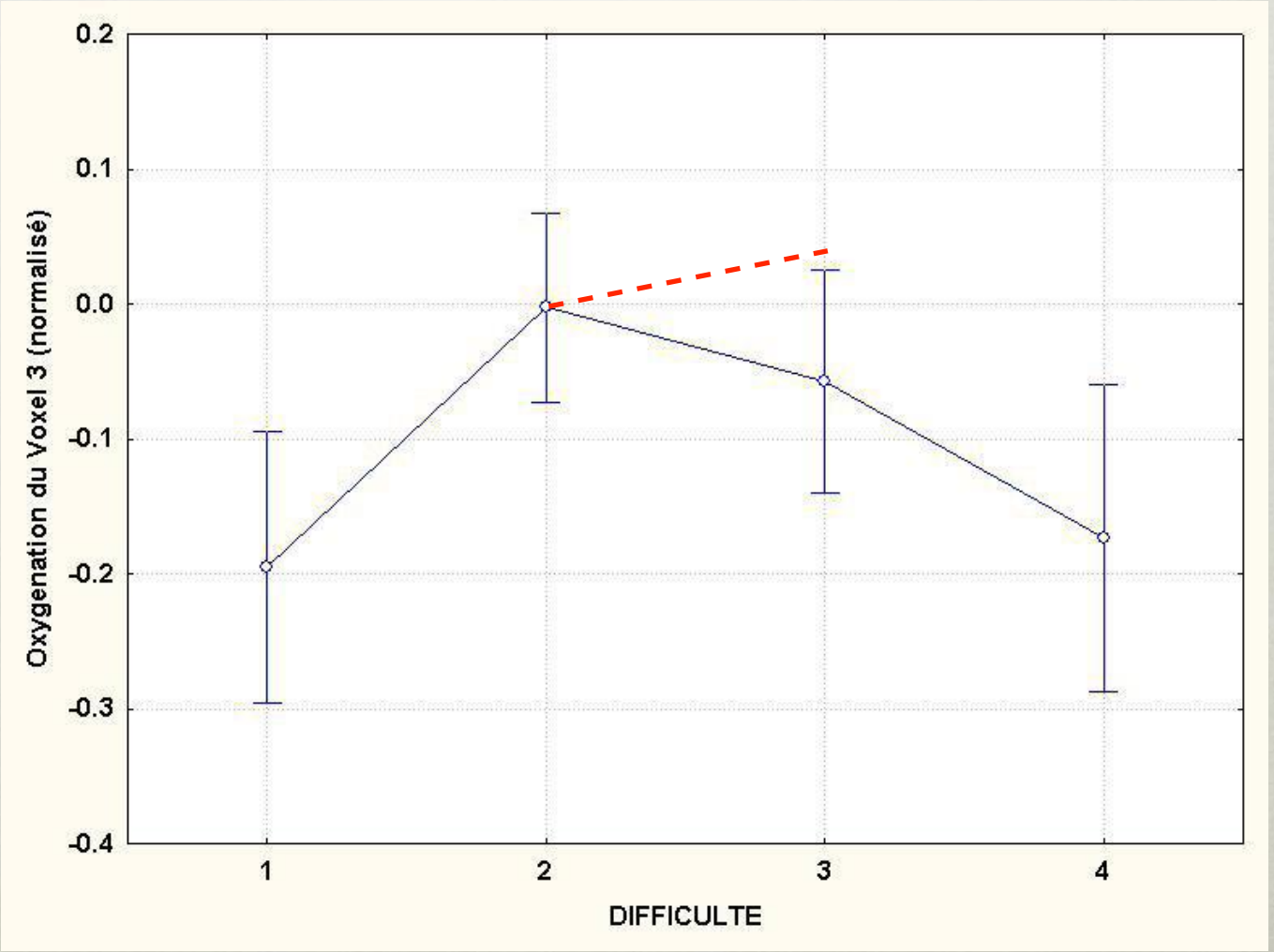

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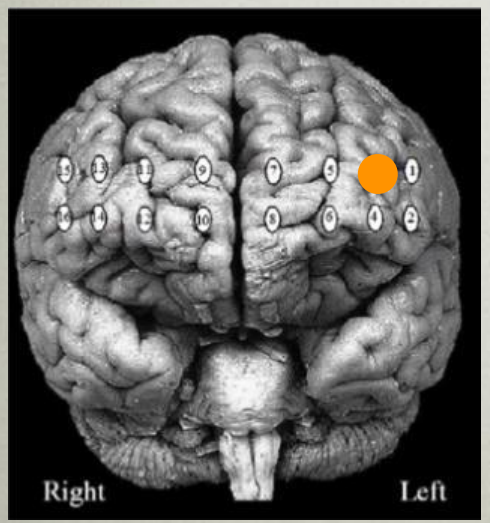

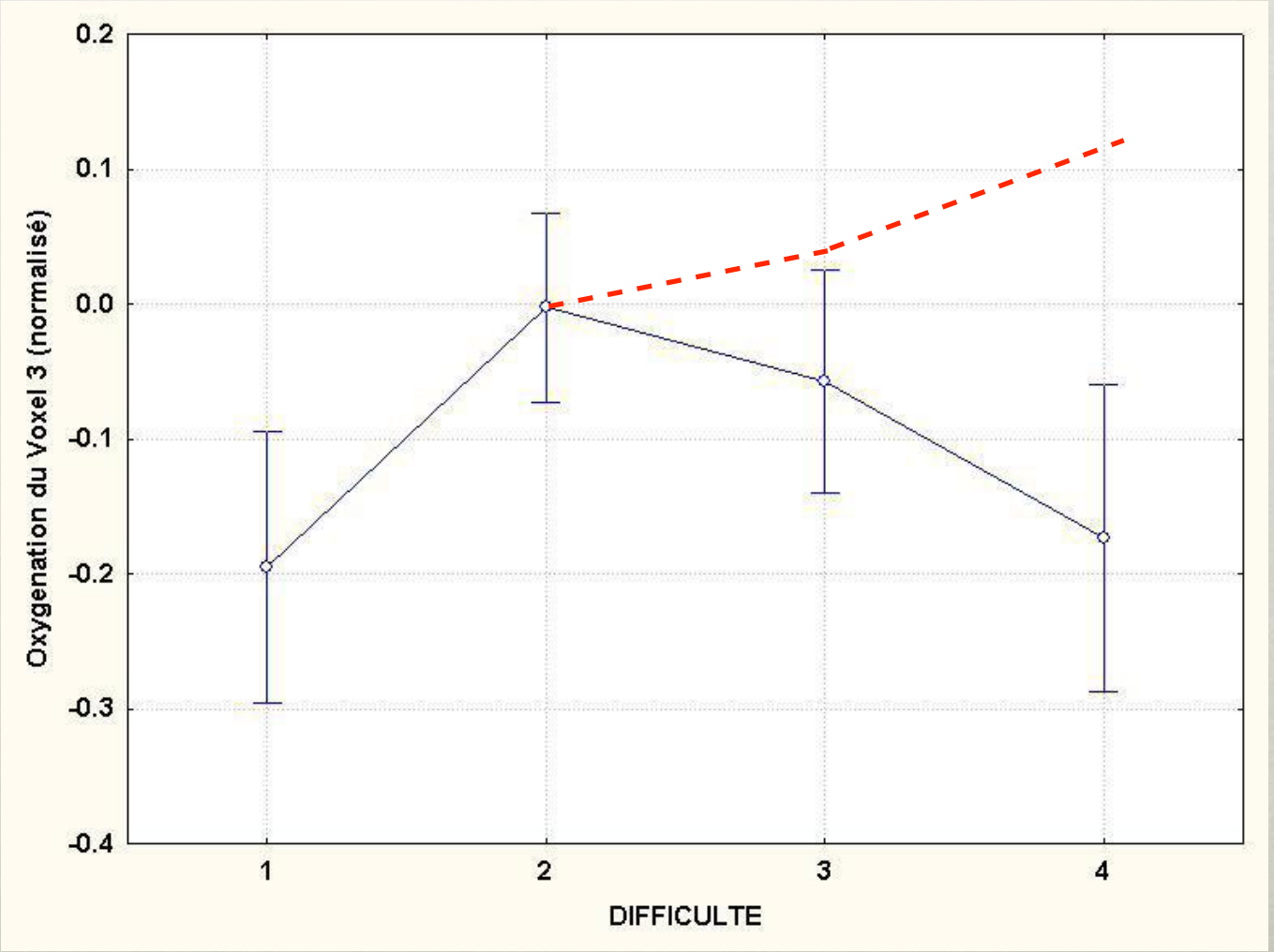

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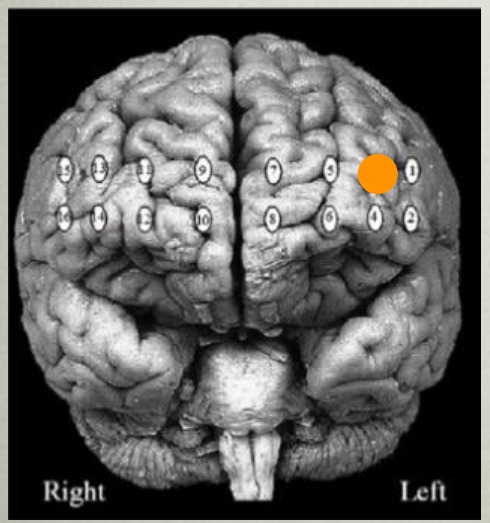

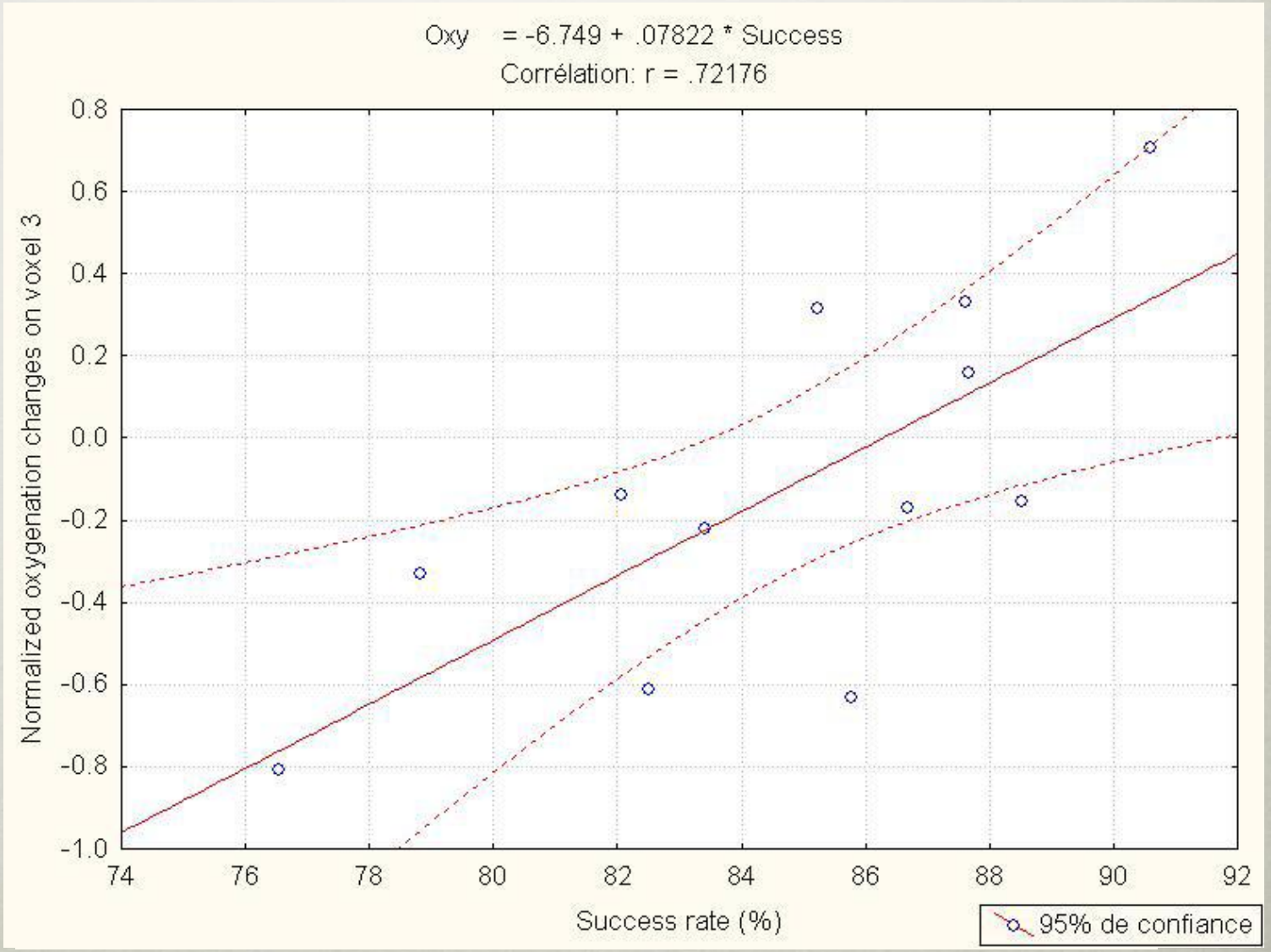

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Inattentional deafness

"Inattentional deafness" in aeronautics

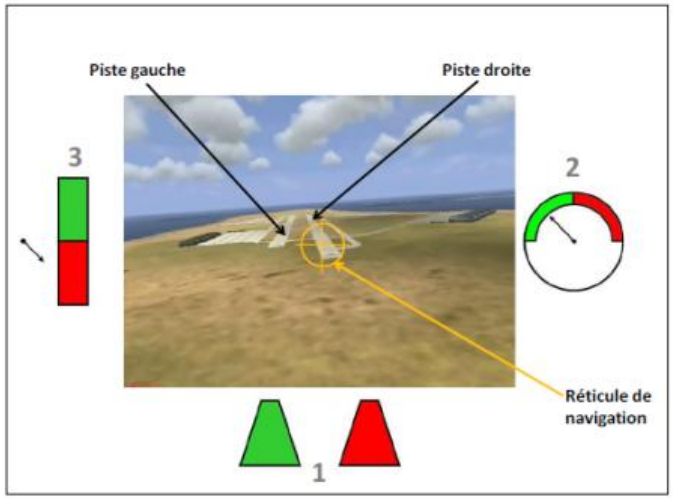
Inattentional deafness

- "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, Sinett et al. 2007, ...) especially under high visual load (Mc Donald et Lavie, 2011)

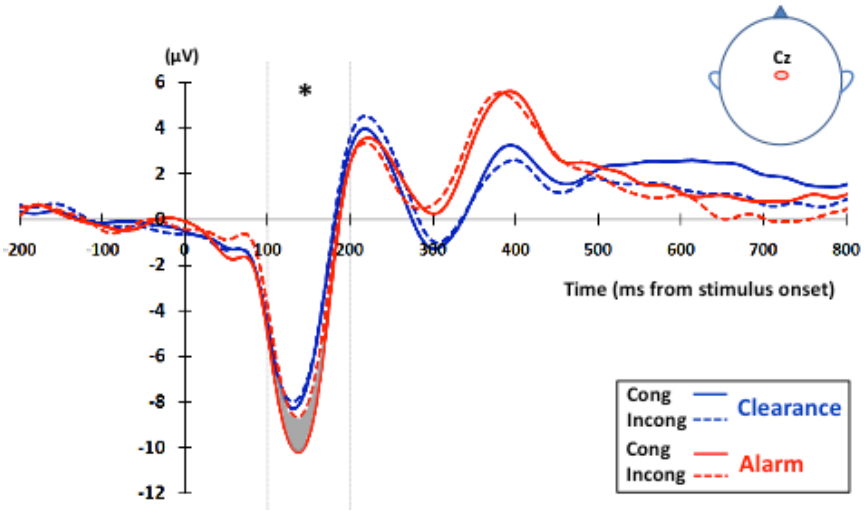
→ ***Inattentional deafness***

- 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)

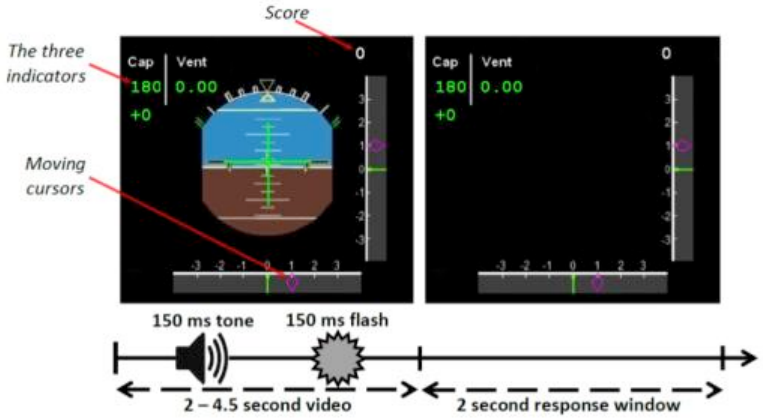
EEG: Inattentional Deafness



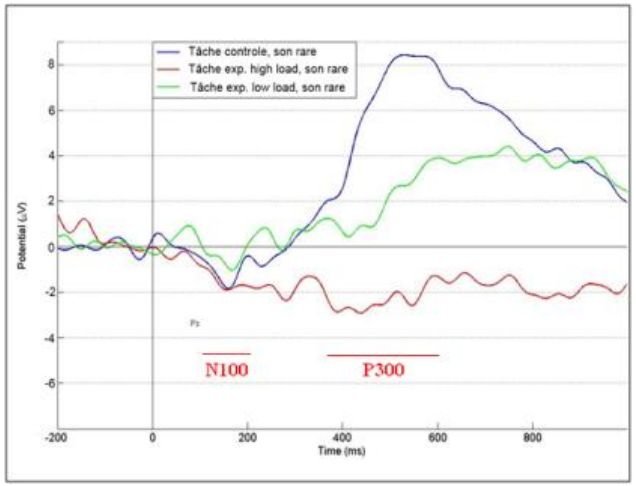
Audiovisual conflict/N100



Scannella, S., Causse, 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., Causse, M.. et al. (in Revision). P300 as an indicator of inattentional deafness. *Journal of Cognitive Neuroscience*

Inattentional 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)

[Dehais et al., Human Factors, in Press]

Inattentional deafness : ecological conditions

Cognitive countermeasure

Design of cognitive countermeasures

- Paradox: *How can one "cure" human operators when they face inattentional blindness/deafness, if the alarms/systems designed to warn them are neglected*?

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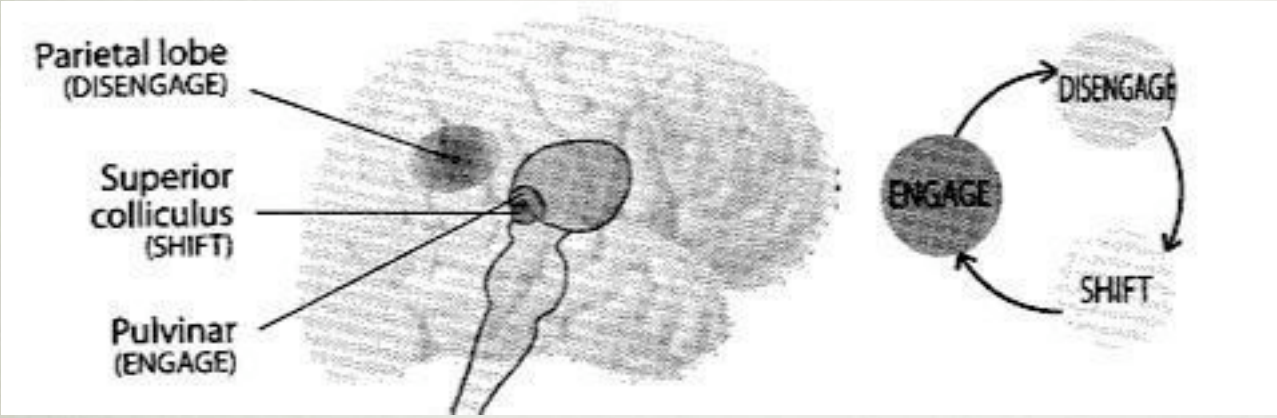
Stressors and emotion affects orienting network [Pecher et al; 10]

Perseveration/attentional impairment



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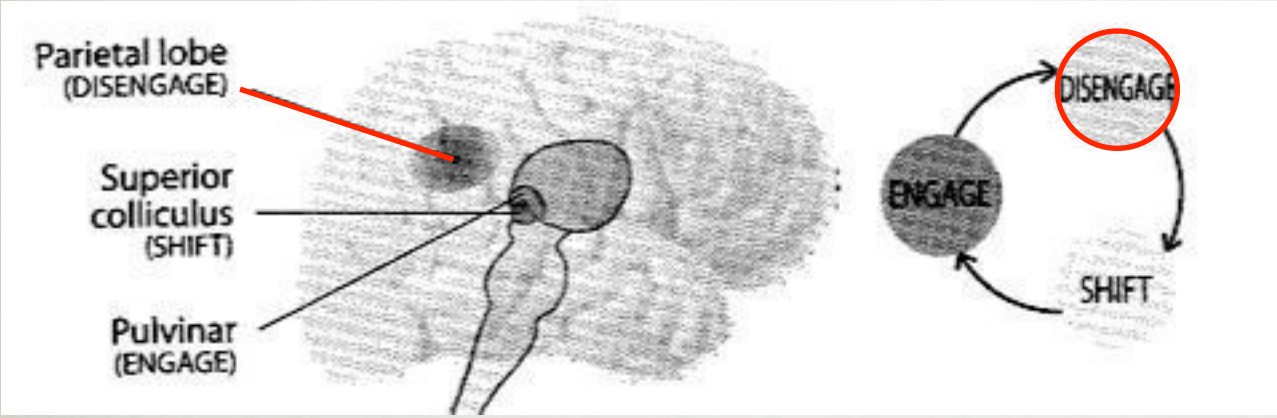

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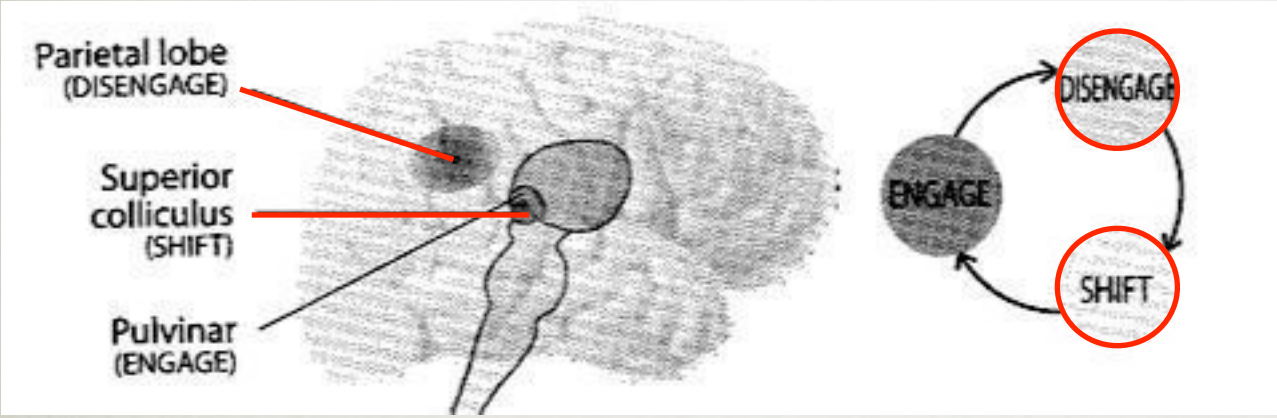

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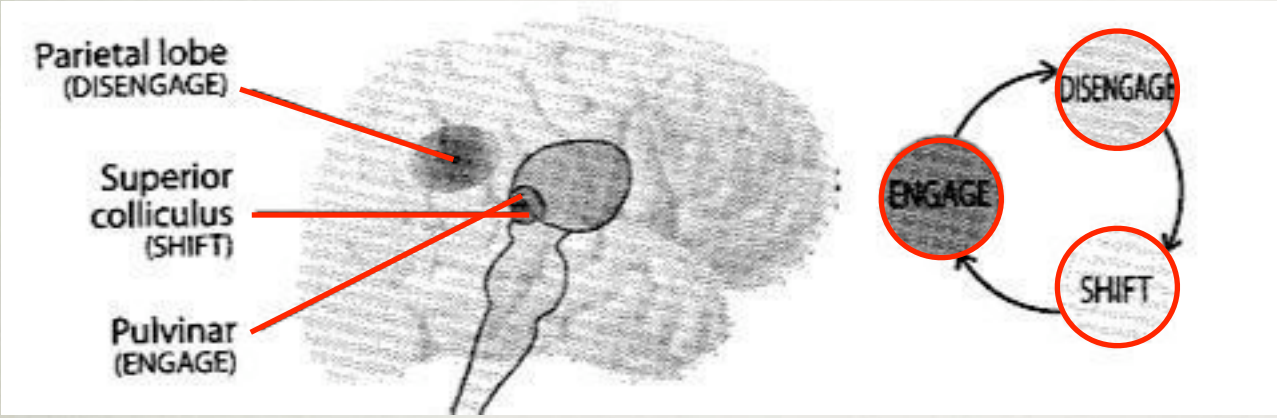

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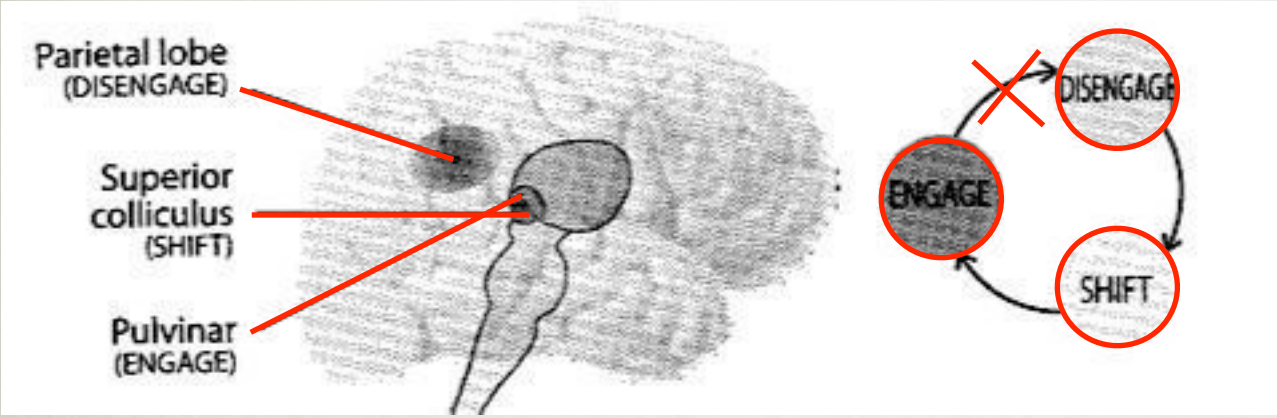

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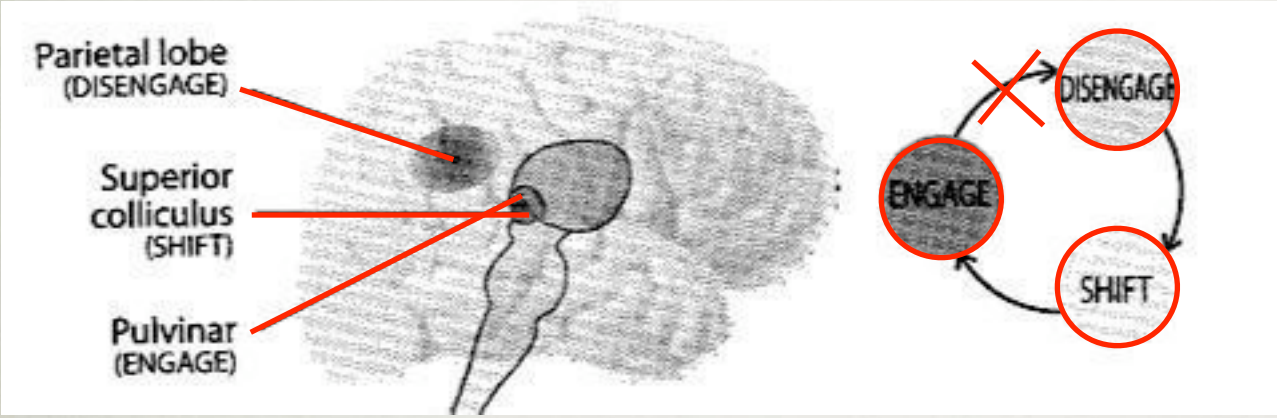

Inability to disengage attentional focus (Pulvinar) : patients (LaBerge, Carter, & Brown, 1992), "stressed" subjects (Tracy, Mohamed, Faro, Tiver, Pinus, & Bloomer, 2000).

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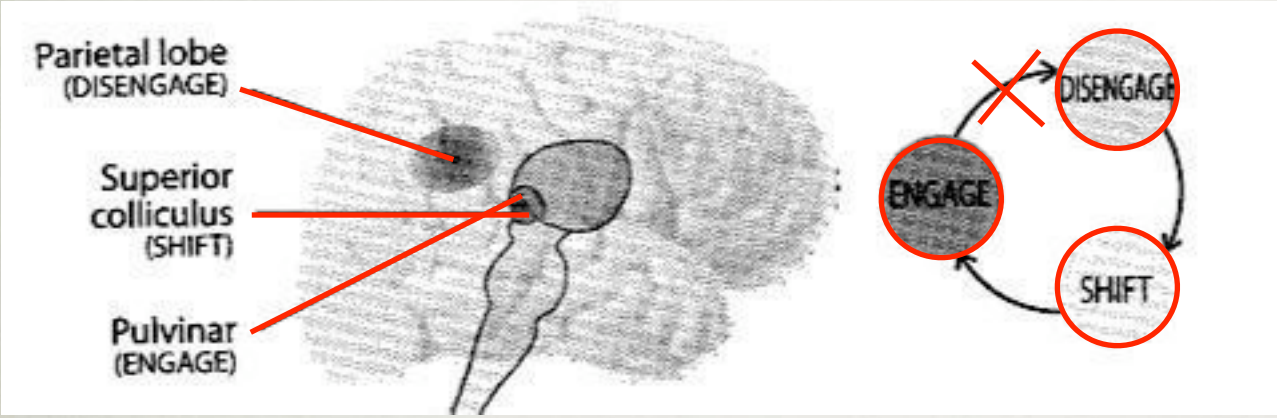

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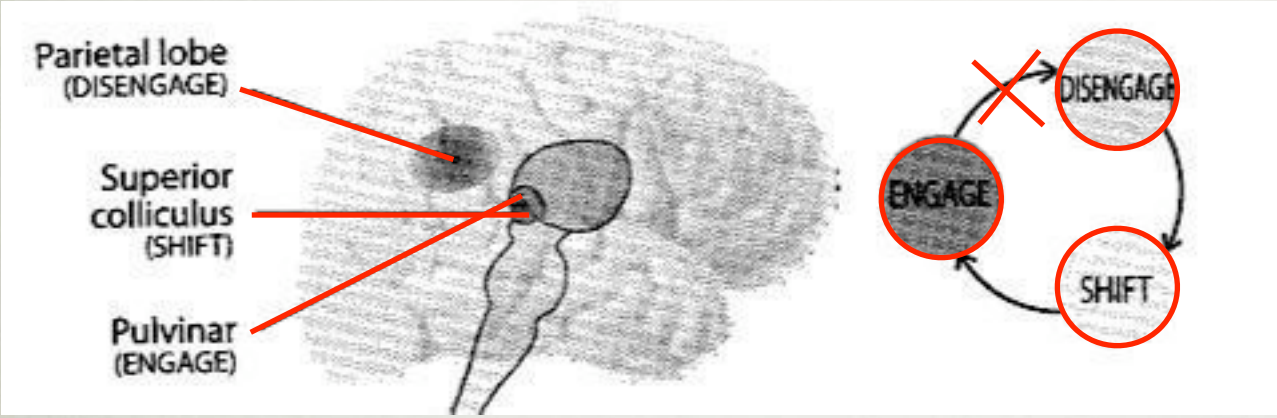

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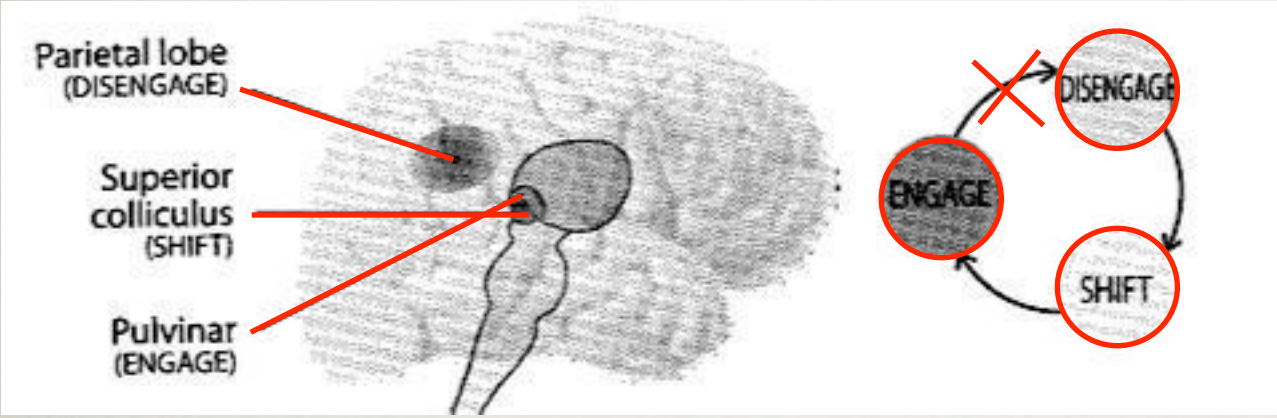

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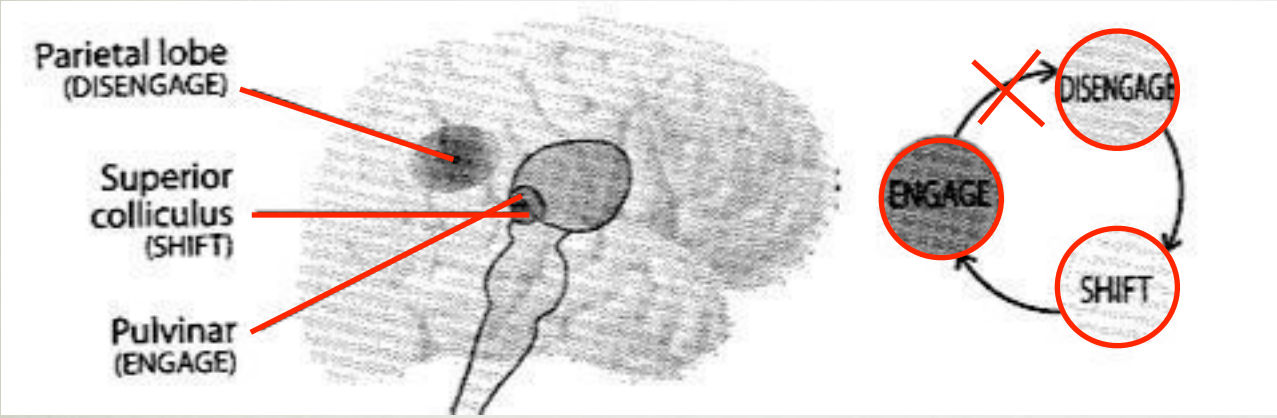

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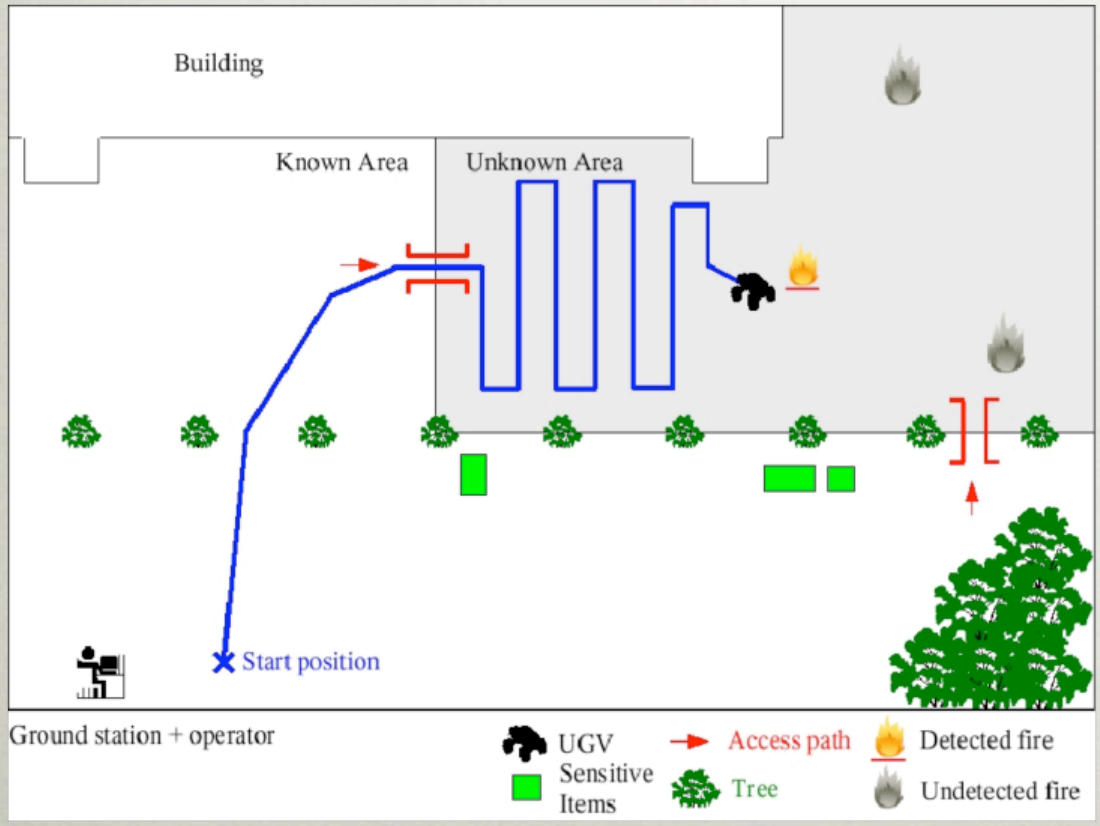
"The GUI disengages/shifts the pilot's attentional focus"

MAIA project (2007-2014)

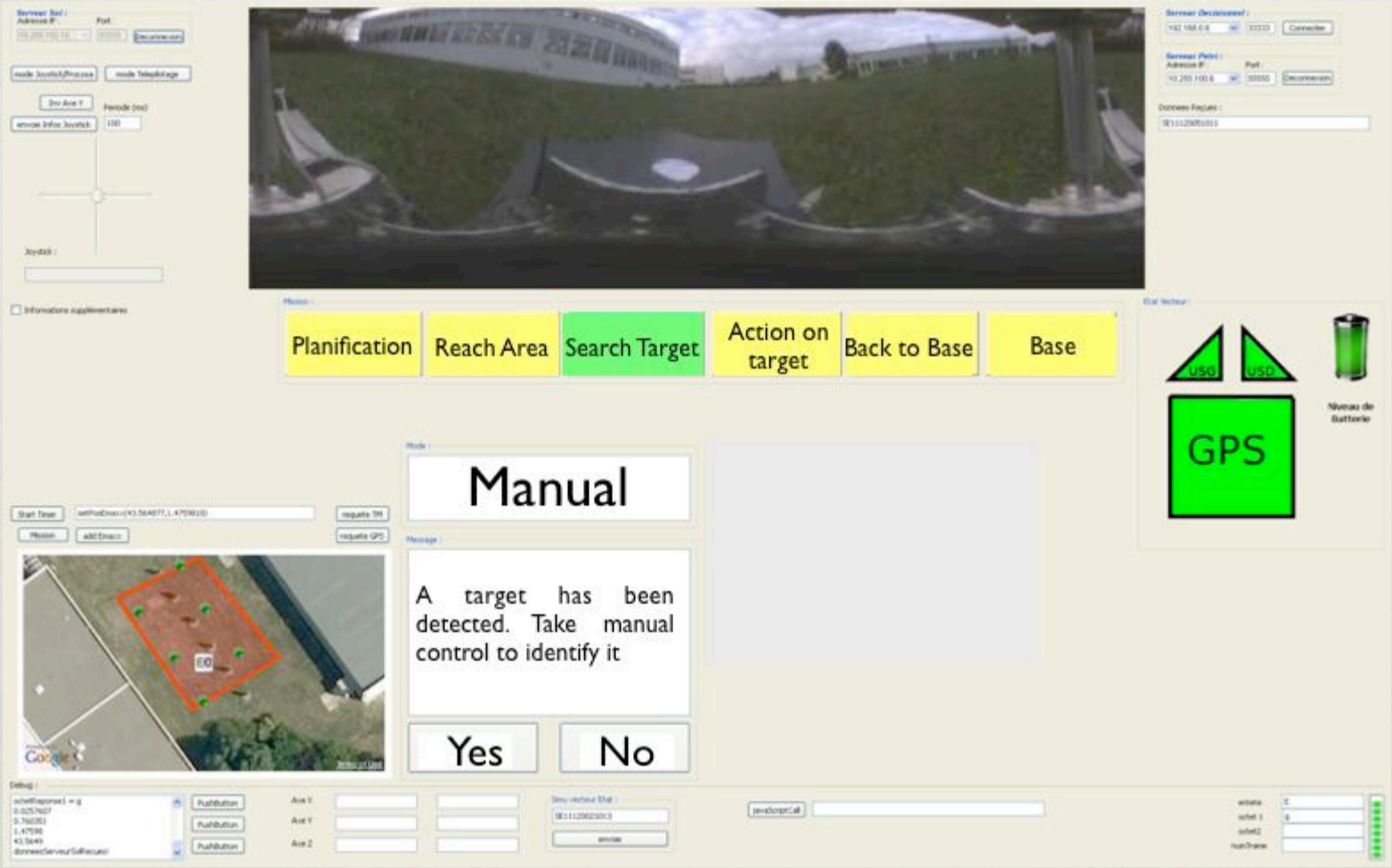
DGA fundings : "modelling cognitive conflicts in human operator/unmmaned vehicles interactions "

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



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

The user's GUI



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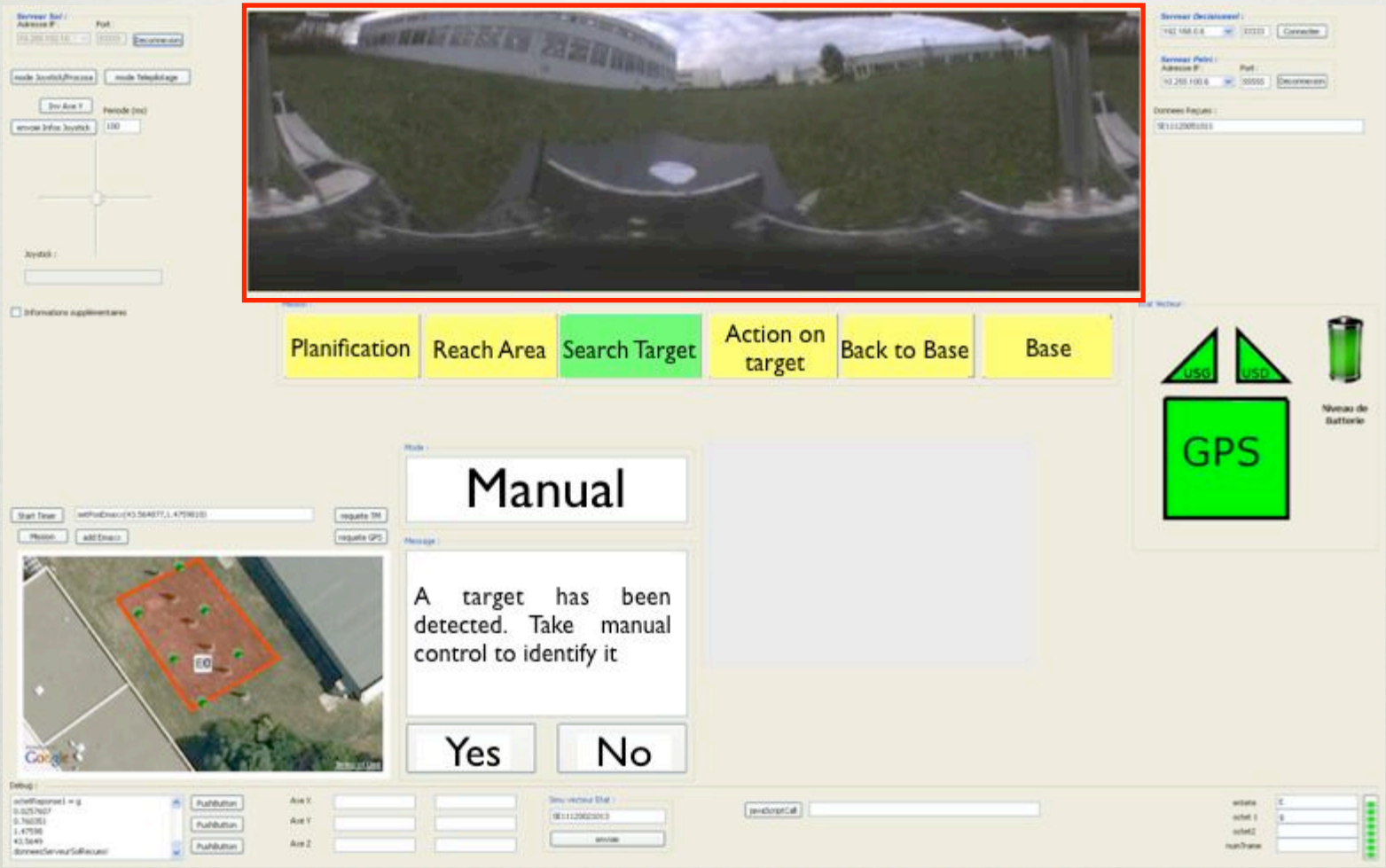
Panoramic video



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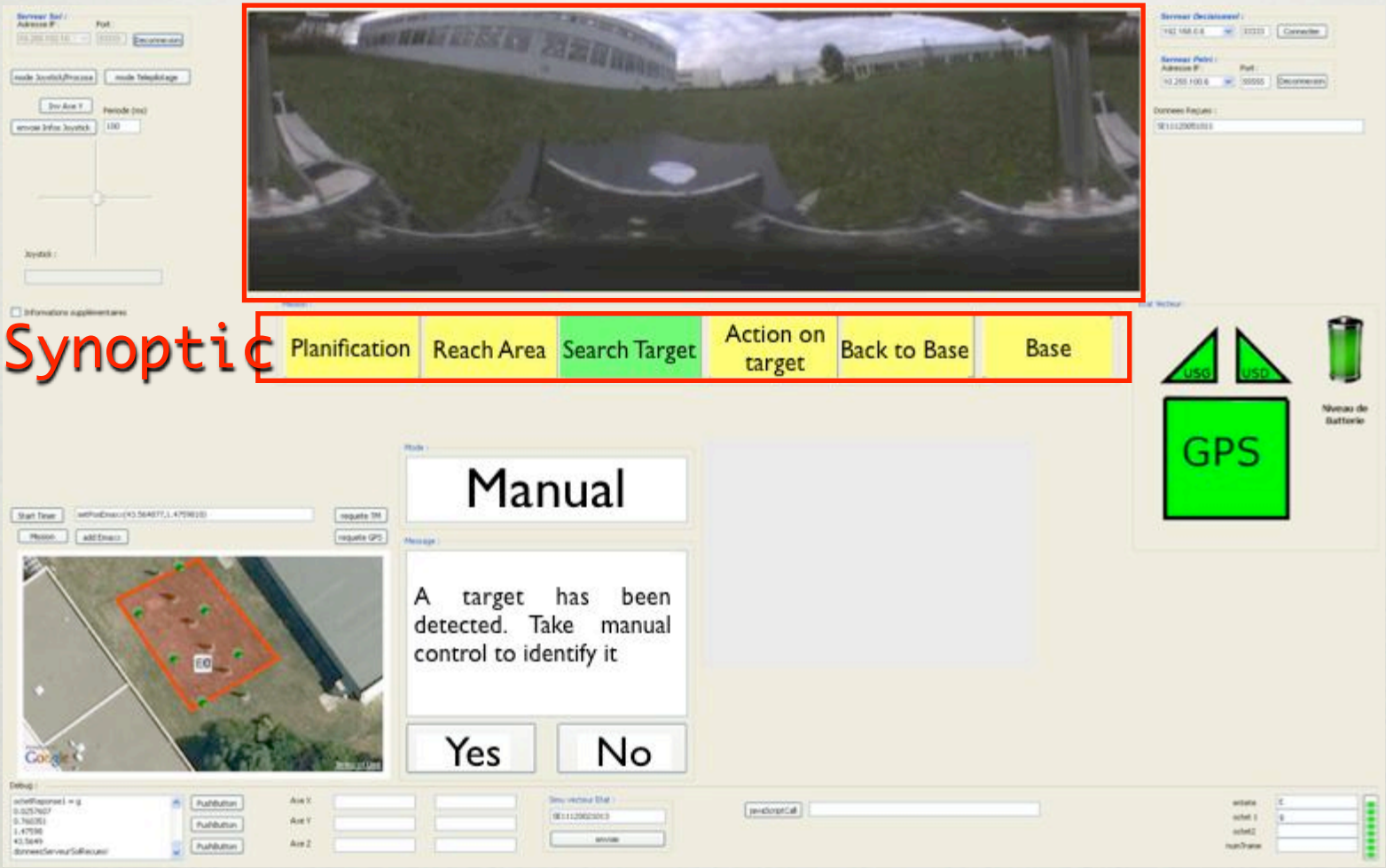

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Panoramic video

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The user's GUI

+ Wizard of Oz

Groupe 1 : No cognitive countermeasures

[Dehais et al., Human Factors, 2011]

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Groupe 11 : Cognitive countermeasures

[Dehais et al, 2012, Human Factors]

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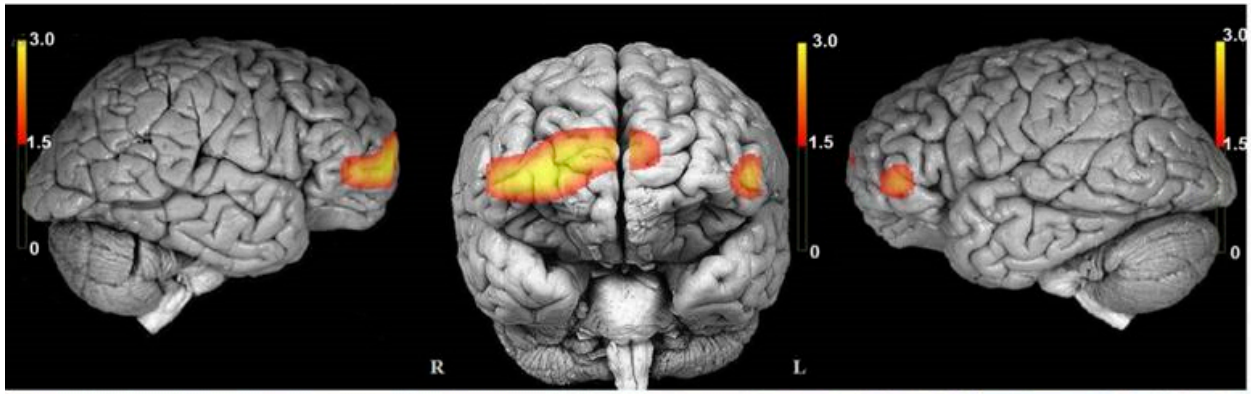
On-line Monitoring

Neurocockpit



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

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"Ecological" Flying Task

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Machine Learning

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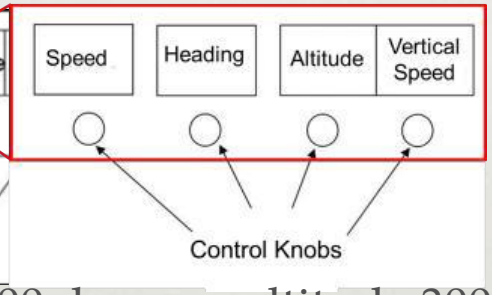

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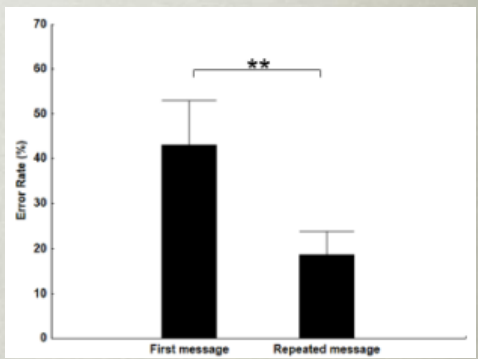
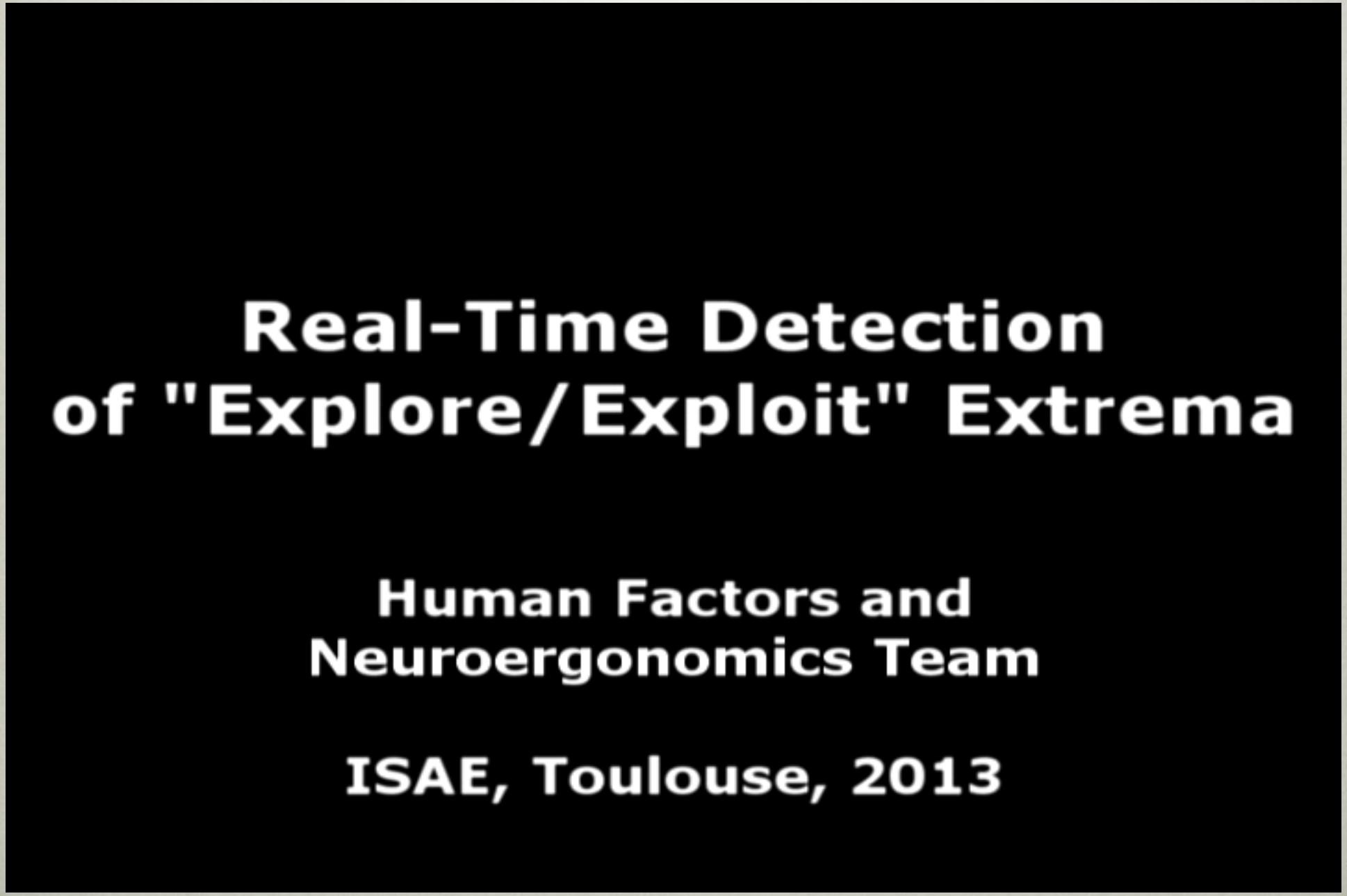


accuracy>70%

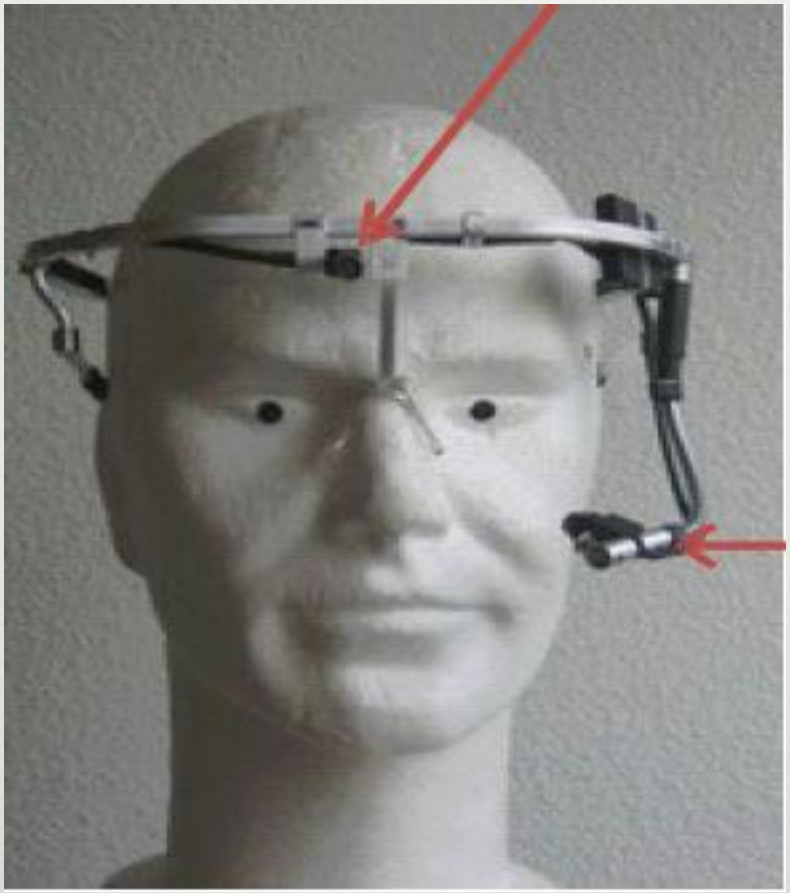
specificity = 80%

Neurocockpit project: eye movement



Go Around Study: BEA/Air France/Airbus

Scene Camera

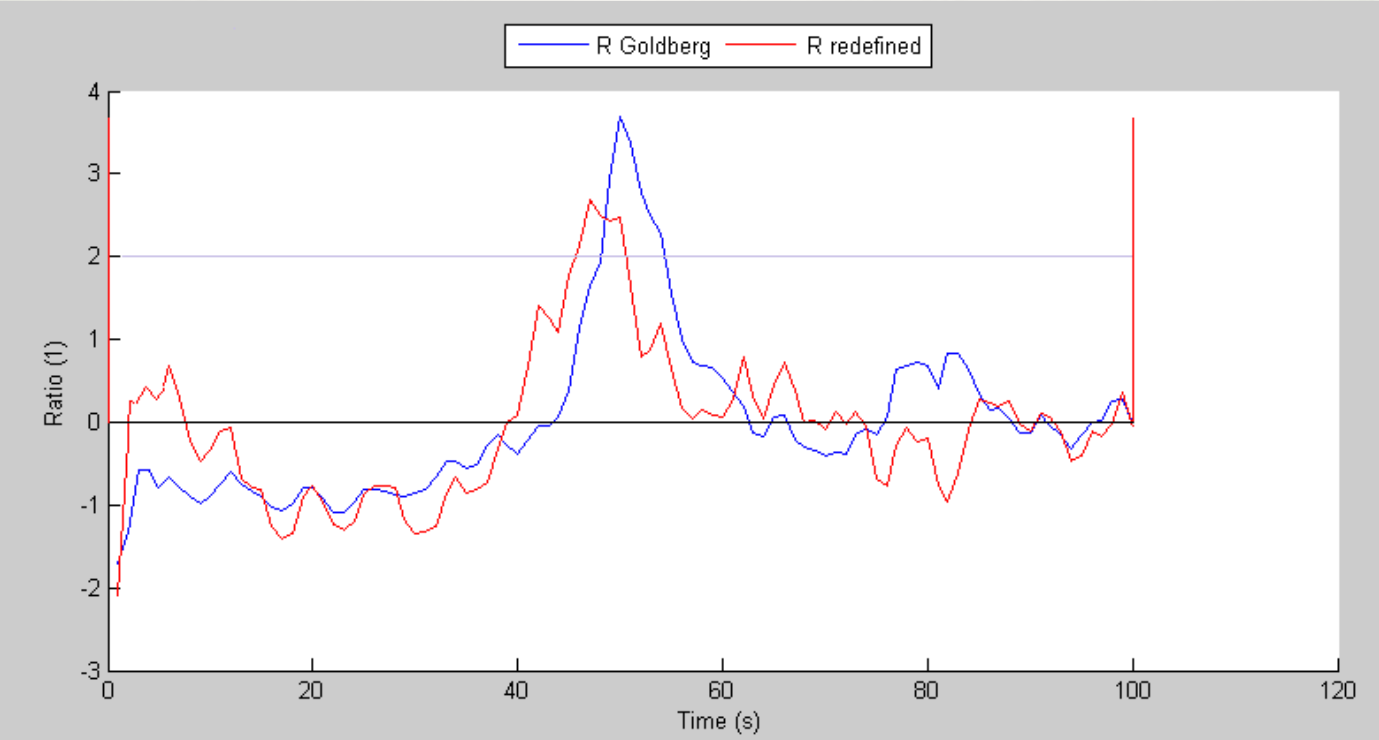


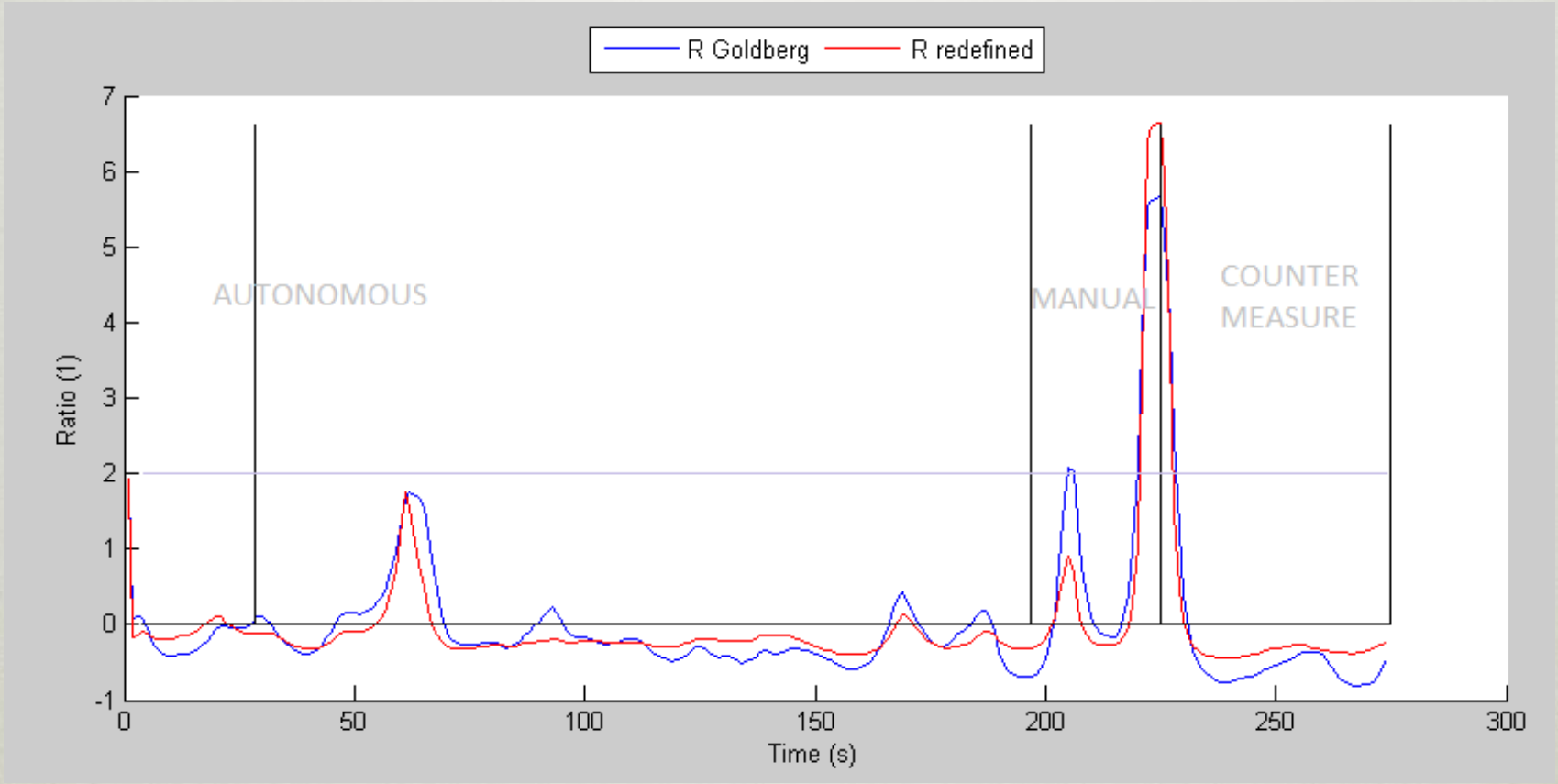
Eye camera

Go Around Study: BEA/Air France/Airbus

2 synchronized eye trackers

Eye metrics : BEA study




R Goldberg
R redefined
AUTONOMOUS
MANUAL
COUNTER
MEASURE
Ratio (1)
Time (s)
7
6
5
4
3
2
1
0
-1
0
50
100
150
200
250
300