Quantitative functional brain mapping imaging using Arterial Spin Labelling for safe neurosurgery

GR Iannotti[1,2], V Ivanova[2], Q Tourdot[3], I Nadin[2], S Momjian[2], KL Schaller[2], KO Lovblad[1], F Grouiller[4,5]

1.Department of Neuroradiology, University Hospital of Geneva
2.Department of Neurosurgery, , University Hospital of Geneva
3.Faculty of Pharmacy, University of Montpellier
4.Swiss Centre for Affective Sciences, University of Geneva
5.Laboratory of Neurology and Imaging of Cognition, Department of Basic Neurosciences, University of Geneva

Rationale

- BOLD signal is widely used in research and clinic to map functional cortex. However, it does not allow for a quantitative measure, and it has several limitations associated to the variability of the HRF model, particularly affected in cases of altered neurovascular coupling[1]. This can induce false positive and/or false negative activations, which are critical especially when BOLD is used to map brain regions to be preserved in patients who are candidate for brain surgery.
- *Arterial Spin Labelling (ASL)* is an alternative *non-invasive* imaging technique that allows for a direct and *quantitative* measurement of the cerebral blood flow[2](**Fig. 1**). Although ASL demonstrated to locate more directly and more precisely the neuronal activity, it is still only *occasionally* used for *functional* mapping.

Objective

- To validate the spatial specificity of ASL compared to BOLD in healthy subjects during the execution of tasks, before the application on the neurological population and translation in the clinical practice.

Methods

- 30 healthy subjects: [18-60] years old;18 F
- 1st session->MRI:
  - High resolution 3D-T1 (MEMPRAGE, 1mm isotropic)
  - Dual echo pseudocontinuous ASL allowing simultaneous BOLD/ASL acquisition (TR=3500ms, TE1/TE2=10/25ms, label =1500ms, PLD=1000ms, 20 slices =3.2x3.2x3mm)
    - Hand clenching
    - Pneumatic stimulation of thumb
- 2nd session-> neuronavigated TMS (**Fig. 2**):
  - Stimulation of the motor area and motor evoked potentials (MEP) measure (thumb and little finger)
- Distances of the coordinates of maxima of activation:
  - ASL versus BOLD
  - ASL-TMS versus BOLD-TMS

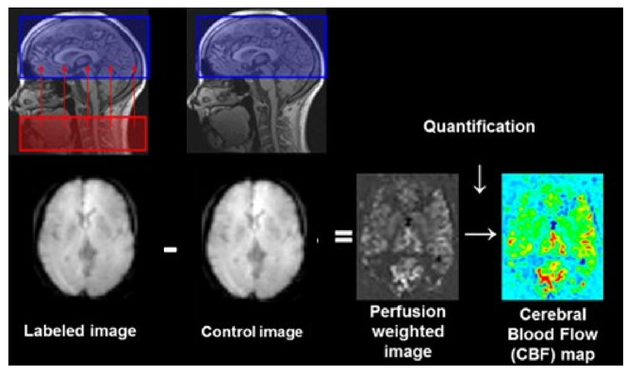

Fig. 1: Principles of ASL. *A radio-frequency inverts the magnetization of the blood. After sufficient time (post-labelling delay) a 'labelled' image is acquired. The same image is then acquired without labelled blood (control). From the pair-wise subtraction of labelled and control images, a quantitative measurement of the perfusion can be obtained.*

Results

- In clenching task, for both hands:
  - In respect to BOLD, ASL was found (**Fig.3**, **Fig.4**):
    - More lateral (x direction, axial plane)
    - Significantly more anterior *(*$p<0.05$*)*
    - Significantly deeper ($p<0.001$)
  - The comparison of MRI modalities with TMS, revealed that **ASL** was **significantly closer to TMS than BOLD** (**Fig. 4**)
    - Along the posterior-anterior direction
    - Along the ventral-dorsal direction
- In pneumatic stimulation (**Fig.5**) group-analysis showed that in respect to BOLD, ASL was
  - More towards the midline, in agreement with literature[3,4]
  - More anterior
  - Deeper

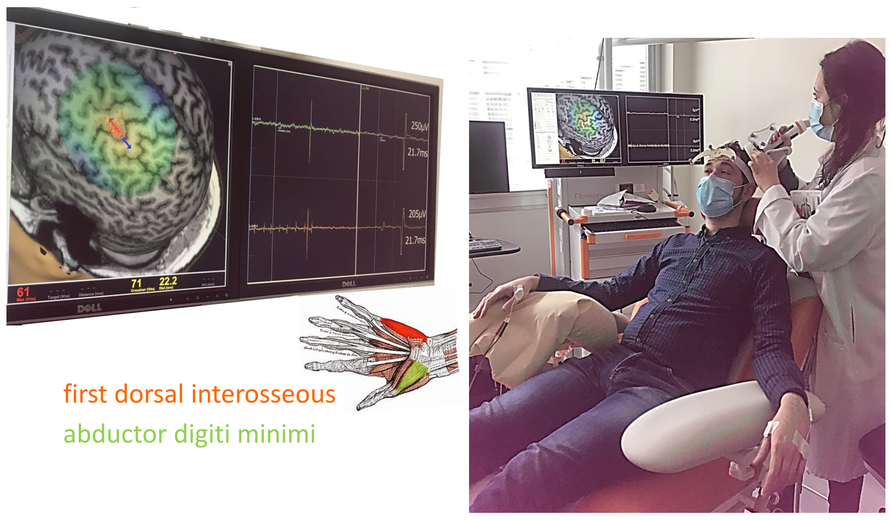

Fig. 2: TMS session. *The motor area corresponding to the Ω region in the pre-central sulcus is mapped by using TMS stimulation (105% of the measured subject's specific motor threshold). Points of significant activations (**Fig 4**) are defined according to the MEP amplitude measured for the thumb and the little finger, during the stimulation.*

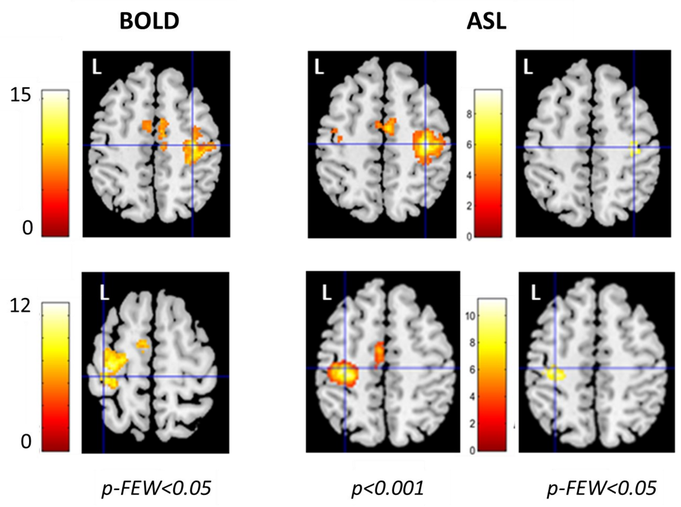

Fig. 3: Group-analysis of clenching motor task. Despite ASL has lower signal-to-noise ratio than BOLD, in the group-analysis the main ASL cluster survived at p-FWE<0.05.

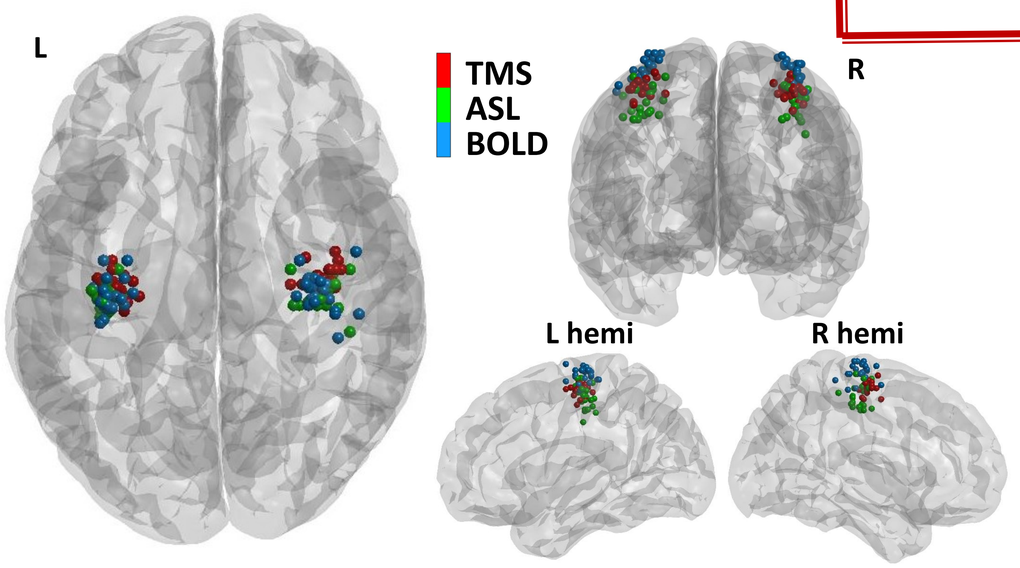

Fig. 4: Inter-modality activation at individual level during hand clenching. *For each participant, blue and green spheres (equal size) centered on the MNI coordinates of global maxima of BOLD and ASL activations are shown; in red, the MNI coordinates of the points with highest motor evoked potential during TMS.*

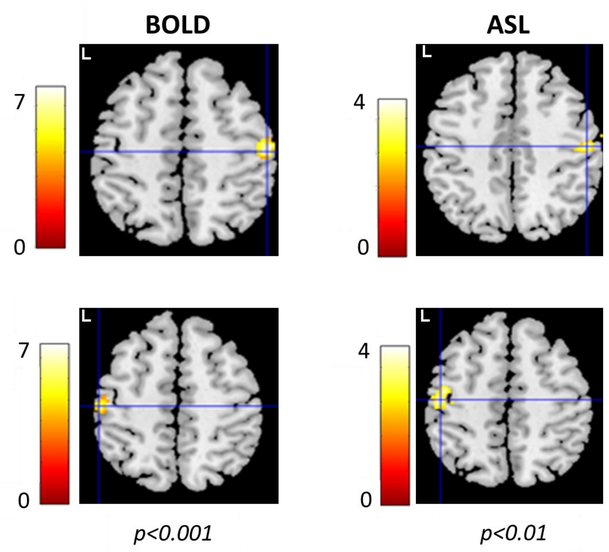

Fig. 5: Group-analysis of pneumatic stimulation. This task produced weak results for either BOLD and ASL. However, ASL localises more specifically than BOLD along the sulcus.

Discussion

Our results show the higher spatial specificity of functional ASL in respect to BOLD for the mapping of somatosensory and motor areas. Functional ASL could potentially substitute or at least complement fMRI studies based on BOLD. In the clinical context, functional ASL could be a valid alternative to BOLD, specially to target in the pre-surgical workflow eloquent cortex to be preserved during neuro-surgery.

References

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Giannina.Iannotti@unige.ch