Quantification of CBF Changes in the Human Brain During Moderate Exercise With pCASL

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Target Audience: Researchers interested in application of ASL in the study of cognitive function associated with practice of physical activity.

Purpose: Recent studies in humans have shown that moderate exercise might be associated with improvement in cognitive function and stimulation of brain plasticity, which might be related to a delayed onset of dementia[1]. Furthermore, physical activity also prevents some chronic diseases such as diabetes and obesity[2]. To study the physiological impact of exercise on the human brain, the measurement of cerebral blood flow (CBF) is often used[2]. However, the standard methods, such as the Kety-Schmidt method or transcranial Doppler ultrasound, share a lack of spatial information providing only global whole brain values of CBF (gCBF). MRI has the potential to provide such spatial information with quantitative accuracy using arterial spin labelling (ASL), a technique that has been validated against the gold standard ^{15}O-H_2O PET technique[3]. The aim of this work is to investigate the effects of moderate exercise on the CBF measured with ASL in the healthy brain.

Methods: The representative data shown in Fig. 1 were acquired from a healthy volunteer using a dedicated exercise setup in a 3T MR-PET scanner capable of hybrid operation. A cardiologic module (Ergospect GmbH, Tyrol, Austria) was introduced into a 3T MR-BrainPET scanner (Siemens, Erlangen, Germany). The module consists of two components: one inside the scanner room, the other outside the scanner room. The component inside the scanner room is a pedal ergometer with two press plates (one for each foot) that simulates stepping. This module measures the force and distance during exercise and transmits this information to the second component – a computer system that controls the resistance of the movement by adjusting an air pressure to maintain a constant power-output during the period of exercise. The subject was carefully positioned in the scanner and the ergometer was adjusted in order to allow full extension of the leg and to avoid the knees touching the scanner bore. The ergometer system was calibrated before the measurement. The experiment protocol used to evaluate CBF during moderate exercise consisted of the following blocks: 1) ASL measurement without exercise, 2) ASL measurement during moderate exercise 3) ASL measurement during the recovery period following exercise. For the first and third period, the ergometer was positioned and the feet of the subject were fixed to the press plates. The position of the legs was ensured to be at the same location to avoid any induced CBF differences. In the second block, the moderate exercise was defined as 35% of the maximum power tolerated by the subject (a warm-up period of 3 min. was given before ASL measurement). A pseudo-continuous arterial spin labeling (pCASL) sequence with a 1.4 s labeling train[4] and a 1.5 s delay was used. Specific sequence parameters of 2D EPI-based readout were: FA/TE/TR=90°/14 ms/4 s, matrix = 64×64×23, resolution = 3.4×3.4×6 mm^3. Each ASL measurement with 60 repetitions and 30 pairs of label-control pairs was performed with motion correction (MoCo) in 4 min. During moderate exercise the delay was shortened to 1 s due to the increase of blood velocity[5]. In addition, a T1-weighted MPRAGE anatomical image was acquired. CBF maps were evaluated using ASLtbx[6] after realignment and smoothing with a 3 mm Gaussian kernel.

Results: Figure 1 shows the locations of the areas with increased (upper row) and decreased (lower row) CBF during and after exercise. These images were obtained by subtracting the baseline CBF from the CBF of each other block. Despite the enhancement of the vascular structures, it is also possible to observe an increase of CBF in the motor cortex both during and after the exercise. Two volumes of interest (VOIs) with a threshold of 50% of the maximum CBF were defined and evaluated in the moderate exercise CBF (modVOI, red contour) and recovery CBF (recoVOI, green contour) (Table 1). Motion of less than 1 mm in z direction and a pitch less than 1 degree was found during the experiment.

Table 1. Cerebral blood flow values (ml/100g/min) for different volumes of interest.

Block	gCBF	modVOI	recoVOI
Baseline	33.30	37.54	44.57
Moderate Exercise	35.45	71.99	64.49
Recovery	31.69	51.98	57.85

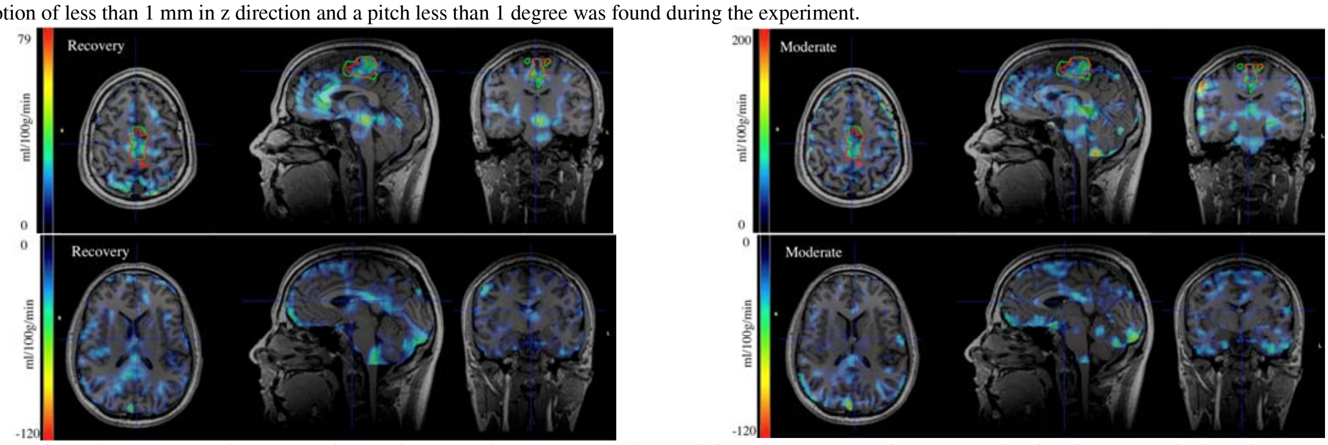

Figure 1. In the upper row the increased CBF during moderate exercise (left) and during recovery (right) compared to baseline is overlaid on the anatomical images. In the lower row the decreased CBF during moderate exercise (left) and during recovery (right) compared to baseline is presented. The volumes modVOI (red) and recoVOI (green) are also presented.

Discussion: The presented gCBFs are in agreement with those detected using standard methods, with an increase of gCBF during exercise and a decrease afterwards[2]. Changes of CBF in the region of the motor cortex were found both in a similar trend as gCBF but with higher amplitude (Table 1). One common limitation for using MRI in measurements involving exercise is the induction of motion artefacts. In our work, we focused on moderate exercise to avoid substantial motion artefacts in the images. Nevertheless, for higher intensity exercises respiratory motion and head movement may result in severe motion/susceptibility artefacts. Further validation is taking place with a large number of subjects.

Conclusion: We have shown that with this particular setup, it is possible to obtain CBF maps using pCASL during moderate exercise and that an increase of CBFs was found during both the exercise and recovery period compared to baseline. Furthermore, the experiments were carried out in a hybrid 3T MR-PET system which could be used to simultaneously measure glucose consumption, for example.

References: 1. Erickson KL and Kramer AF, Aerobic exercise effects on cognitive and neural plasticity in older adults, Br J Sports Med. 2009;43(1):22-4; 2. Ogoh S and Ainslie PN, Cerebral blood flow during exercise: mechanisms of regulation, J Appl Physiol. 2009 Nov;107(5):1370-80; 3. Zhang K and Herzog H, et al. Simultaneous Arterial Spin Labelling MRI and H_2O^{15} Position Emission Tomography, Proc. in ISMRM. 2013; 4. Okell TW et al., Cerebral blood flow quantification using vessel-encoded arterial spin labeling, J Cereb Blood Flow Metab. 2013; 33(11):1716–1724; 5. Fisher JP et al. Cerebral perfusion, oxygenation and metabolism during exercise in young and elderly individuals J Physiol. 2013 Apr 1;591(Pt 7):1859-70; 6. Wang Z, et al, Empirical ASL data analysis using an ASL data processing toolbox: ASLtbx, Magn Reson Imaging, 2008, 26(2):261-9.