Investigation of Baroreflex Autonomic Control by Spectral Coherence of fMRI Independent Components and Neck Suction Stimulation Signal

Matteo Mancini[1,2], Eugenio Mattei[2], Federica Censi[2],
Barbara Basile[3], Marco Bozzali[3], Giovanni Calcagnini[2]

[1]Department of Engineering, Università degli Studi di Roma Tre, Rome, Italy
[2]Italian National Institute of Health, Rome, Italy
[3]Neuroimaging Laboratory of Santa Lucia Foundation, Rome, Italy

Abstract

Functional Magnetic Resonance Imaging (fMRI) has proved to be a powerful technique for the analysis of the central autonomic control on the cardiovascular system. The carotid stimulation represents a viable non-invasive tool to investigate the brain areas involved in the central autonomic control. In this paper a resting-state fMRI protocol has been carried out on normal subjects, during bilateral carotid stimulation by neck suction using a custom MRI-compliant device. Two suction levels (60 mmHg and 10 mmHg) were applied in two consecutive sessions, using rectangular pulses with a duration of 8 s spaced by 4 s.

To detect the brain region involved in processing the carotid baroreceptor efferent signals, a combined approach of independent component analysis (ICA) and spectral coherence (SC) has been used: ICs have been estimated from fMRI data using the GIFT toolbox, the SC between each IC and the neck stimulation signal has been computed, and finally we have identified the stimulus-related ICs on the basis of the spectral coherence at the frequency of interest. SC greater than 0.5 were observed in all but one subjects, during the neck suction at 60 mmHg. The SC significantly dropped during the stimulation at 10 mmHg.

Frequency analysis of the neck suction stimulation signal in conjunction with ICA of fMRI can identify the brain structures involved in the central processing and integration of afferent signals from the carotid baroreceptors in healthy human subjects.

1. Introduction

Carotid baroreceptors play an essential role for short-term control of blood pressure and may also be implicated in its long term control. These mechanoreceptors function as the sensors in a negative feedback control system that regulates the beat-to-beat changes in arterial pressure modulating the autonomic neural outflow. Stretching of carotid baroreceptors causes an increase in afferent neuronal firing which results in a reflex-mediated increase in parasympathetic nerve activity and decrease in sympathetic nerve activity. Afferent signals from the carotid baroreceptors, as well as from other peripheral sensors (arterial aortic and lung receptors, to name a few) are processed at central level. Afferent–efferent integration and central command of efferent activity is managed by the brain via the Central Autonomic Network (CAN) [1]. Functional Magnetic Resonance Imaging (fMRI) has proved to be a powerful technique for the analysis of the central autonomic control on the cardiovascular system [2], [3]. The carotid stimulation by neck suction represents a viable non-invasive tool to investigate the brain areas involved in the central autonomic control [4].

2. Materials and methods

In this paper a resting-state fMRI protocol has been designed: carotid stimulation has been performed by neck suction with a custom MRI-compliant device previously described [5], [6]. Bilateral carotid stimulation was delivered, using rectangular pulses of 8 seconds, spaced by 4 seconds, to avoid the adaptation of baroreceptors. Such strategy yields a repetition frequency of 0.083 Hz, making it a reasonably efficient design for fMRI study. Two suction pressures were used in two different sessions: 60 mmHg and 10 mmHg [7]. Each recording session lasted 480 seconds (40 stimulation pulses). Whole brain fMRI signals were collected at the Neuroimaging Laboratory of Santa Lucia Foundation in Rome, using a 3T Siemens Allegra scanner, with an echo-planar T2* sequence, with BOLD contrast, and a repetition time of 2.08 seconds. Twelve healthy right-handed volunteers were examined, all men. The protocol was approved by the local ethics committee. fMRI data were preprocessed in order to realign and filter the images using the software SPM5 (Statistical Parametrical Mapping, http://www.fil.ion.ucl.ac.uk).

To detect the brain regions involved in processing the carotid baroreceptor efferent signals, a combined approach of independent component analysis (ICA) and spectral coherence (SC) has been used.

Independent components (ICs) have been estimated from the fMRI dataset using GIFT 2.0a (Group ICA of fMRI Toolbox, http://mialab.mrn.org). We estimated 20 ICs using group analysis, and then retrieved the individual ICs for each subject, using the back reconstruction algorithm also provided by GIFT [8].

Then, we resampled the neck stimulation pressure signal at the repetition frequency of the scanner. In this way, we could compute the SC for each subject: estimation of the SC was obtained using the Welch method, with a rectangular window of 64 samples overlapped by 75%. ICs having a SC > 0.5 at 0.083 Hz were considered as stimulus-related. Finally, we performed a paired Student t-test between each independent component at 60 mmHg and at 10 mmHg in order to identify relevant differences for the population between the two sessions.

3. Results

Figure 1 shows the global spectral content of the 20 ICs obtained from the group analysis. The effect of the stimulation was detectable as a peak at 0.083 Hz during the 60 mmHg stimulation, that nearly disappeared at 10 mmHg. In each subject at least 1 stimulus-related IC was identified in the 60 mmHg stimulation trials (coherence range between 0.55 and 0.91 – Table 1).

The spectral coherence of such components falls below 0.5 during the 10 mmHg stimulation session, in all but two subjects. The ICs numbered 8, 11 and 12 were the IC correlated to the neck suction most recurrent in the population.

The paired Student t-test showed that SC of seven ICs was significantly higher at 60 mmHg respect to 10 mmHg with p-values lower than 0.05, while the ICs numbered 8, 11 and 12 showed a p-value approximately equal to 0.01.

Figure 2 shows the mean (+/- the Standard Error) SC over the population of the 20 ICs at 60 and 10 mmHg stimulation, together with the significance level of the differences (Student t-test for paired data).

Table 1. Stimulus related independent components.

Subject	IC with SC>0.5 @ 60 mmHg	IC with SC>0.5 @ 10 mmHg
#1	1 (0.58),3 (0.60) ,8 (0.72), 12 (0.54)	-
#2	4 (0.53)	.
#3	-	-
#4	15 (0.57)	-
#5	11 (0.73),16 (0.60)	-
#6	1(0.51) , 5(0.51) , 6(0.52), 7(0.76),8 (0.59),14 (0.54)	-
#7	11 (0.76) ,12(0.59), 13(0.60)	-
#8	1(0.72), 13(0.51), 5(0.58), 9(0.62), 10(0.55), 11(0.77), 12(0.64), 14(0.59),19(0.57), 20 (0.54)	-
#9	8(0.69), 20 (0.58)	-
#10	-	1,9,15
#11	8 (0.65)	16
#12	11(0.50), 12(0.51), 15(0.78),18(0.55), 20 (0.52)	-

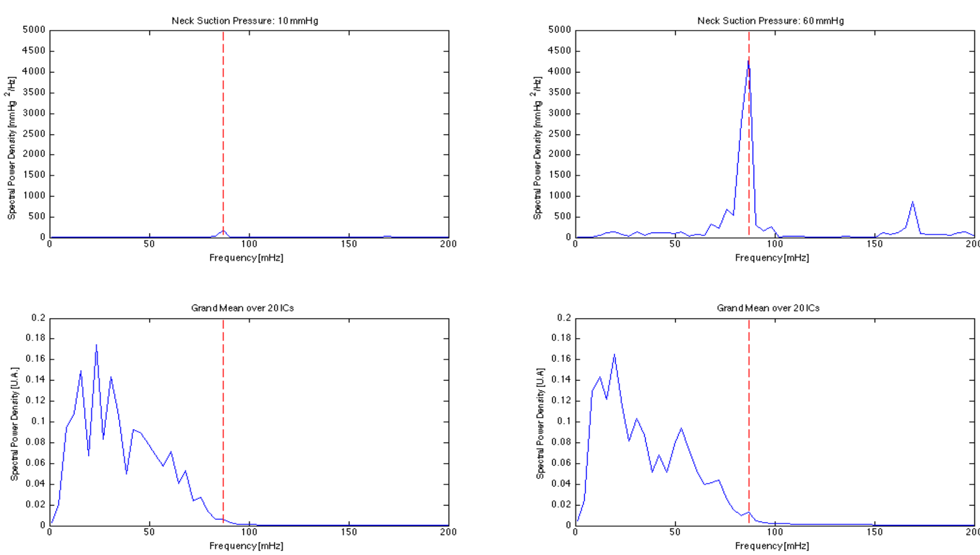

Figure 1. Spectral power densities of the neck stimulation pressure signal in the two sessions (10 mmHg and 60 mmHg) and mean spectral power density of the 20 independent components in the respectively sessions.

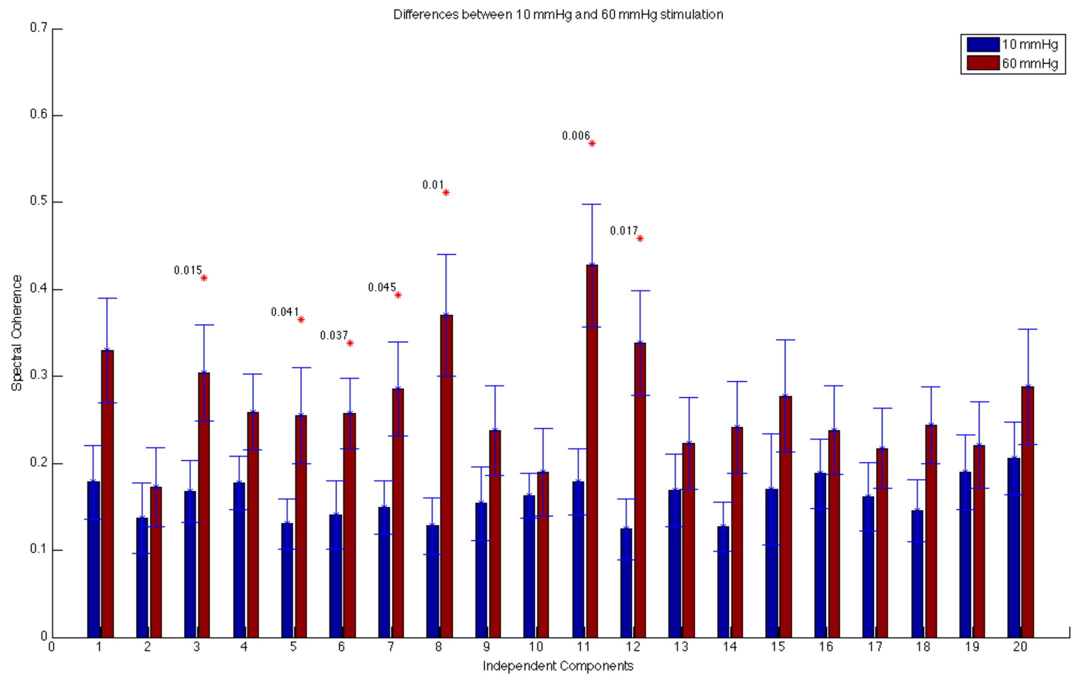

Figure 2. Mean standard coherence of the independent components over the 12 subjects in the two sessions.

4. Discussion and conclusions

Stretching of carotid baroreceptors causes an increase in afferent neuronal firing which results in a reflex-mediated increase in parasympathetic nerve activity and decrease in sympathetic nerve activity. Few data are available regarding the brain regions involved in such processing.

Frequency analysis of the neck suction stimulation signal in conjunction with ICA of fMRI allows the investigation of the brain structures involved in the central processing and integration of afferent signals from the carotid baroreceptors in healthy human subjects. The results obtained show that the stimulus applied is detected in all but one subjects, even if not always in the same independent components. These interindividual variability needs further investigation, before attempting to draw conclusions on the areas involved in controlling and processing the efferent carotid baroreflex signals.

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Address for correspondence.
Matteo Mancini
Department of Engineering
Università degli Studi di Roma Tre
Via Vito Volterra, 62
00154 Rome – Italy
matteo.mancini@uniroma3.it