

Effect of the scanner background noise on the resting brain networks detected by functional magnetic resonance imaging

Efeito do ruído de fundo do tomógrafo nas redes cerebrais de repouso detectado pela imagem por ressonância magnética funcional

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Abstract

Resting state studies by fMRI are carried out in order to identify the brain networks responsible for their basal functioning, which are known as resting state networks. Although considered to be in rest, subjects are unavoidably under a massive charge of environmental acoustic noise produced by the magnetic resonance imaging equipment. Our aim was to verify if the massive auditory information input could mask the “real” resting state networks. The functional volumes were acquired when seven naïve subjects (four women) had their eyes opened under default echo planar imaging (EPI) sequences or during soft-tone sequences (slew-rate reduction), as allowed by a Philips Achieva 3T magnetic resonance imaging scanner. The sound pressure level difference between the default and soft sequences reached 12 dB. Experimental sessions consisted of two runs of seven minutes each under different levels of noise. The sequence of conditions was counterbalanced between subjects. The functional volumes were pre-processed in BrainVoyager and submitted to self-organizing group Independent Component Analysis (sogICA). The influence of the higher noise level was evaluated by identifying the BOLD components and by comparing the functional volumes of the five representative resting state networks under each condition (random effects – Independent Component Analysis). The results show that a lower level of noise may uncover functionally wider components. A *t*-test showed that the high noise condition induced significantly higher BOLD signal in the posterior cingulate cortex only. However, lower noise levels induced higher BOLD activity in the bilateral parietal lobule, bilateral superior frontal gyrus, and insula. Yet, the motor resting state network seems to be wider under low noise, reaching auditory areas in the temporal cortices, and an oscillatory component on the thalamus was identified in the low noise condition. The results indicate that a compromise should be taken into account when studying rest, balancing between noise reduction, and speed of acquisition.

Keywords: fMRI, default-mode network, resting state, acoustic noise, ICA.

Resumo

Os estudos relativos ao estado de repouso pela imagem por ressonância magnética funcional (fMRI) são realizados para identificar as redes cerebrais responsáveis pelas função basal das redes neurais, conhecidas como redes em estado de repouso. Embora considerados em repouso, os indivíduos inevitavelmente recebem uma alta intensidade de sons do ambiente produzidos pelo equipamento de ressonância magnética. O objetivo deste estudo foi verificar se a informação auditiva recebida poderia mascarar as “verdadeiras” redes em estado de repouso. Os volumes funcionais foram obtidos quando sete indivíduos (quatro mulheres) tiveram seus olhos abertos em seqüências pulso ecoplanares (EPI) ou durante seqüências silenciosas (redução da taxa de variação), utilizando um *scanner* de ressonância magnética Philips Achieva 3T. A diferença no nível de pressão do som entre o EPI padrão e a silenciosa chegou a 12 dB. As sessões experimentais consistiam de duas etapas de sete minutos com diferentes níveis de ruído. A seqüência das condições foi contrabalanceada entre os indivíduos. Os volumes funcionais foram pré-processados no programa BrainVoyager e submetidos a análise de componentes independentes em grupos auto-organizados (sogICA). A influência do nível mais alto de ruído foi analisada pela identificação dos componentes BOLD e pela comparação dos volumes funcionais das cinco redes cerebrais em estado de repouso representativas para cada condição (efeitos aleatórios da análise independente dos componentes). Os resultados mostram que um nível menor de ruído pode revelar componentes funcionalmente mais amplos. Um teste *t* mostrou que o ruído intenso induziu sinais BOLD mais intensos somente no córtex cingulado posterior. Porém, níveis menores de ruído induziram maior atividade BOLD no lobo parietal bilateral, no giro frontal superior bilateral e na insula. Além disso, a rede motora de repouso parece ser mais ampla sob ruídos baixos, alcançando áreas auditivas no córtex temporal, e um componente oscilatório no tálamo foi identificado sob ruído baixo. Os resultados indicam que um compromisso deve ser considerado ao estudar o repouso, ponderando-se a redução do ruído e a velocidade da aquisição.

Palavras-chave: fMRI, rede de modo padrão, estado de repouso, ruído acústico, ICA.

Introduction

It was observed that, when the voluntary action is required, some areas of the brain are paradoxically deactivated. This finding led the researchers to suggest that there is an organized mode of brain function, known as “default mode”, as a baseline that is partially suspended during one specific behavior of directed action¹. Two explanations were raised to account for these deactivations during targeted actions. Firstly, these brain areas could be deactivated following the reallocation of attentive resources for tasks that require extreme focus of attention. Secondly, areas may be deactivated because they are related to the basal monitoring of the external environment or linked to free-thought processes, such as: mind wandering or sensory-motor awareness².

The subtleness in the functioning of the brain basal state and its relationship to the external world raised a concern about the influence of the environmental factors, once they could mask deactivations related to basal monitoring of the external environment or free-thought. The effect of the scanner background noise (SBN) may be intertwined in the functional data, avoiding the identification of the real resting state networks (RSN). It has been shown that the brain activity was differently modulated depending on the type of acquisition. Continuous sampling, that is, image acquisition under continuous noise showed that the brain activity was different from sparse sampling, when echo planar imaging (EPI) volumes were acquired after periods of silence. The SBN seems to have suppressed the default network components, like the medial prefrontal cortex, posterior cingulate, and precuneus. The authors state that the noise does not alter the spatial distribution of the default network, but it influences its magnitudes in a non-linear fashion³. This is also true for the working memory functioning⁴, as shown by the higher recruitment of attentive resources under high noise conditions. BOLD activation was higher in the cerebellum, frontal cortex, fusiform cortex and lingual gyrus, and lower in the anterior cingulate and putamen. As found in another study assessing SBN⁵, the higher attentive demand to hear sentences under noise resulted in a higher activation in the left temporal and inferior parietal cortices. The authors conclude that silent EPI sequences would be more adequate for auditory perception studies and its applicability depends on the regions of interest in the brain.

If from one side the RSNs seem to be influenced by environmental factors, the same is not true if the subjects rest with their eyes opened, open with fixation or with the eyes closed⁶. The most relevant finding in this study is the observed behavioral competition between focused attention and free-thought processes. While posterior cingulate and medial prefrontal cortices oscillate in phase, the intraparietal sulcus shows out of phase activity with the former areas, which evidences a functioning pattern of anti-correlated fluctuations.

Along with direct correlation, another common way of analyzing data for intrinsic patterns, without assuming any

a priori condition, is the Independent Component Analysis (ICA)^{7,8}. The algorithm is based on an adaptive filter that maximizes the independence of the temporal series components by the progressive decreasing of mutual information. The ICA algorithm is applied on all voxels in order to separate the set of information in networks with coherent and maximally independent fluctuations⁹. Group results can be achieved by applying a clustering method on ICA maps of different subjects, which allows to identify the common activity across individuals¹⁰.

Materials and methods

Our approach consists in using the fMRI acquisition to verify if the massive input of auditory information shall mask the true brain RSNs. Data acquired with EPI sequences producing two different levels of SBN were compared. First, data were submitted to the ICA. Then, the components under each noise level were grouped by a self-organizing clustering algorithm. Finally, the RSN maps under each noise level were compared in order to show which areas presented significant differences, indicating if the sound pressure produced by the different EPI sequences were influencing resting state results.

fMRI acquisition

The functional volumes were acquired when seven naïve subjects (four women) had their eyes opened under default EPI sequences or during soft-tone sequences (slew-rate reduction), as allowed by a Philips Achieva 3T magnetic resonance imaging (MRI) scanner. The acquisition of functional images was accomplished with a standard eight-channel head coil. Echo-planar images had the following parameters: 200 volumes, 29 slices in ascending order, 4 mm slice thickness, voxel size 1.83x1.83 mm, slice time 66 ms, FOV=240x240 mm, FH=95 mm, and TR/TE=2000/30 ms. The silent sequence was designed by setting to maximum level in maximum the “soft tone” parameter offered by the MRI tomograph, which decreases the gradient slew rate leading to lower coil vibration levels during acquisition. The high noise condition was done with “soft tone” parameter turned off. The difference between the sound pressures in each scanner setting reached the order of 12 dB, as evidenced by a recording done with a microphone connected to the inbuilt MRI apparatus communication device. The only difference between the two acquisitions was related to the slew rate and consequent lower noise, while repetition time and other parameters were kept constant. After functional scans, each subject was scanned for the acquisition of anatomical 3D T1-weighted images (TR=9.7 ms; TE=4 ms; flip angle 12°; matrix 256x256; FOV=256 mm; 1 mm slice thickness; voxel size 1x1x1 mm).

Experimental procedure

Experimental sessions consisted of two runs of seven minutes each under two different levels of noise. The sequence

of conditions was counter-balanced between subjects. Volunteers were instructed to keep their eyes opened while looking steadily through the head coil mirror. The field of vision included the outside of the scanner bore and a curtain over the control room window. The functional volumes were pre-processed and submitted to self-organizing group ICA (random effects sogICA) in BrainVoyager. The difference of the noise levels was evaluated by comparing the maps of five categories of RSNs under each sound pressure level.

fMRI data analysis

Data were processed in BrainVoyager (Brain Innovations, The Netherlands). Functional volumes were corrected for 3D motion with reference to the first volume. Subjects that showed movements larger than 2 mm were excluded. Slice order correction and co-registration to the anatomical volume were done before standardization into the Talairach space. After linear drift filtering, functional data entered the ICA algorithm. BOLD components were identified depending on the fingerprint of each map¹¹, leading to a classification as published in a previous

research¹². Components, which showed high spectral densities between 0.02 and 0.05 Hz, high values of clustering and skewness, high temporal and spatial entropy, high lag-1 autocorrelation and low kurtosis, were selected and considered as a component related to BOLD signal. The number of voxels in each region of interest indicated by the ICA under each noise level was compared in a bi-causal *t*-test. Voxels with significant differences were identified in the Talairach atlas and they are presented in the next session.

Results

The RSNs were identified here as the following, as categorized in a previous paper¹¹:

- default-mode network (RSN1);
- bilateral visual cortices (RSN3);
- fronto-parietal network (RSN2);
- bilateral motor and auditory cortices (RSN 4 and 5);
- anterior cingulate cortex (RSN6).

Figures 1 and 2 present the networks found in our study, pointing out each RSN category. A pair-wise comparison between the five maps under each noise condition showed that the high noise condition induced significantly higher BOLD

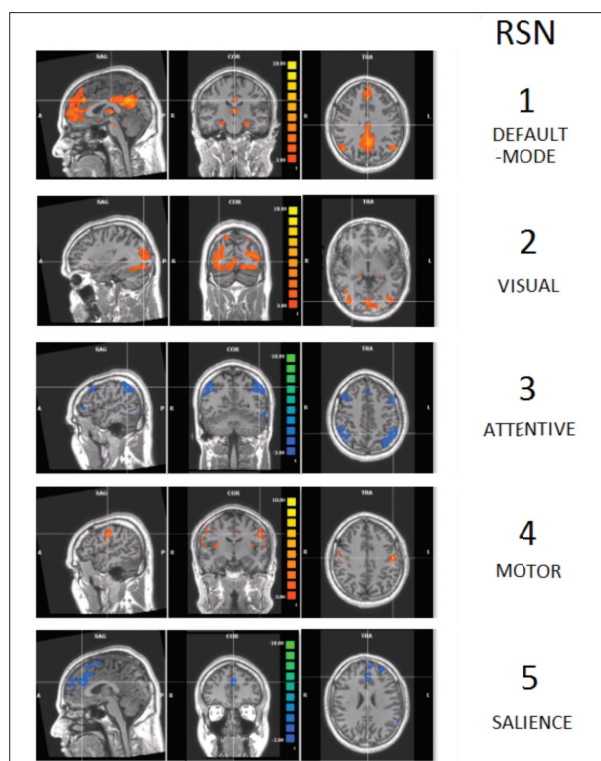


Figure 1. Independent Component Analysis maps calculated on the data during standard acquisition (loud noise, soft-tone parameter off). Numbers indicate the resting state networks as defined in a previous paper¹¹: 1. default-mode network, internal processing; 2. retinotopic occipital cortex, visual processing; 3. dorsal attentive network, goal-directed action; 4. sensory motor cortices, motor control; 5. pre-frontal cortex, self-referential mental activity. The color scales on the Independent Component Analysis maps are arbitrary and they are not related to positive or negative levels of activation. Maps show *t*-values between 3.0 and 10.

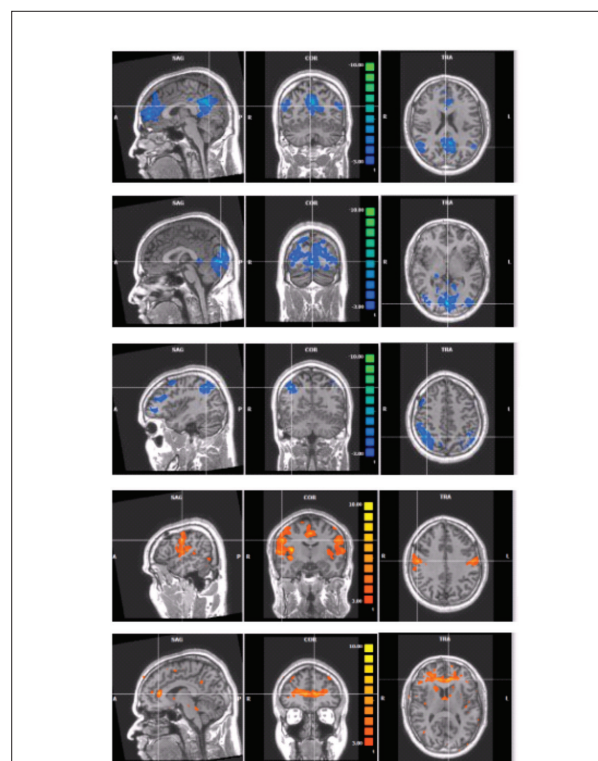


Figure 2. Independent Component Analysis maps calculated on the data during soft-tone acquisition (low noise level). Numbers indicate the resting state networks as defined elsewhere¹¹. The color scales on the Independent Component Analysis maps are arbitrary and they are not related to positive or negative levels of activation. Maps show *t*-values between 3.0 and 10.

signal in the posterior cingulate cortex, while the soft-tone sequence induced higher BOLD activity in the bilateral parietal lobule, bilateral superior frontal gyrus, and insula (Table 1).

Visual inspection of each RSN under different sound pressures indicates that, apart from RSN 1 (default-mode network - DMN), lower level of noise has uncovered components that are spread over a larger area of the cerebral cortex.

As shown in Table 2, the number of voxels in each group component is higher only for the classical default-mode network. The remaining networks show wider areas of activity under soft-tone acquisition or show the same extension of activation, as it is the case of the dorsal attentive network (Table 2).

Three aspects should be noted in these results. First, the motor RSN shows much wider extensions of activity under lower levels of noise, as denoted by the disparate number of voxels in each environmental condition (Table 2). Second, a component with activity in the thalamus (picture not shown) was identified in the low noise group analysis, while no such activity was evidenced for the standard MRI sequence. Third, the salience network component has significant activity widespread across the cerebral hemispheres during soft-tone acquisition, as it can be seen on the comparison between the maps of Figures 1 and 2 (RSN 5).

Table 1. Brain areas and statistical significance found in the gross pair-wise comparison between resting state independent components under standard and soft-tone acquisitions (Student's *t*-test, bi-caudal).

Higher for soft-tone acquisition ($p < 0.01$)				
Brodman's area	Topographic region	Hemisphere	Voxels	t-value
40	Inferior parietal lobule	Left	528	3.63
40	Inferior parietal lobule	Right	1,163	3.91
13, 22	Insula	Right	1,403	3.92
9	Superior frontal gyrus	Left	473	3.78
6	Superior frontal gyrus	Right	448	3.85
Higher for standard tone acquisition ($p < 0.01$)				
Brodman's area	Topographic region	Hemisphere	Voxels	t-value
30	Posterior cingulate	Right	1,168	4.02

Table 2. Extension (in voxels) of group independent components, depending on the level of acoustic noise produced by the magnetic resonance imaging scanner. Resting state networks (RSNs) on the list are named as defined elsewhere¹¹.

Resting state networks category		Number of voxels (relative proportion)	
		HARD noise	SOFT noise
1	DMN	55913 (0.55)	45273 (0.45)
2	VISUAL	41822 (0.43)	54396 (0.57)
3	MOTOR	8210 (0.13)	55318 (0.87)
4	DORSAL	36940 (0.50)	37273 (0.50)
5	SALIENCE	12170 (0.43)	16021 (0.57)

Discussion

The motivation of this research is the concern about the possible influence of the environmental noise on the organized brain function at rest, mainly represented by the DMN. During the last years, resting state paradigms became the approach of choice of many investigators, given their simplicity and reliability, being applicable on a wide variety of subjects. Thus, the concern about the influence of the acoustic noise on the RSNs comes from the fact that the whole body of research could be looking at no rest at all, but into networks that, in fact, are defending the sensory system from an annoying massive input of the acoustic noise. A previous research was carried out using the "nearest" approach, when periods of rest intertwined with directed behavior were scrutinized for the active brain areas. The present study attempts for the first time to investigate the brain dynamics during pure rest conditions. In a scenario of high acoustic noise, reallocation of attentive resources may be difficult since the basal monitoring of the external environment is saturated. That is, both functions that are suggested for the DMN are under stress.

Our results seem to be in complete accordance with this rationale and as suggested by others. The aversive nature of the loud sound seems to damp the sensorial processes, which shall induce a reduction in the activity in the brain areas related to sensory-motor, auditory, and salience processing. On the other hand, lower levels of sound may favor the free dynamics among the totality of the RSNs, which has a higher place for large oscillatory activity in the motor, auditory and salience cortices with the contribution of the thalamus.

Conclusions

Our concern now, along with the future refinement of the data analysis, is to bring into discussion the implications of applying the soft-tone sequence in the all-day of the research, as a way to permit the appreciation of the "real" RSNs. Our results suggest that the standard level of noise in the all-day resting brain research must be taken into account, once different arrangements of active areas may be found when the scanner room gets less loud and more comfortable. Further research is needed to address the subtleness of such differences, gathering clues from a greater number of subjects or from a group of neurological patients.

Acknowledgments

We thank João Pereira Leite and Jaime Shinsuke Ide for the valuable comments about the approach of our research.

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