Functional Contrast Based on iDQC - Influence of the Correlation Distance

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Introduction

In experiments with intermolecular multiple quantum coherences (iMQC), image contrast is based on dipolar couplings between nuclear spins in different molecules separated by a specific distance (1, 2). This so-called 'correlation distance' may range from 10 µm up to a few millimeters. The correlation distance is defined according to $d_c=\pi/\gamma G_c T$, where G_c and T are the strength and duration of the correlation gradient, respectively (3). A unique feature of iMQC imaging is that the spatial scale of the experiment can be manipulated externally by adjusting this gradient to obtain a specific correlation distance. Intermolecular double-quantum coherences (iDQCs) are more sensitive to local magnetic susceptibility variations than the conventional single-quantum coherence signal, which partly offsets the poor signal-to-noise ratio (SNR). This has already been used to generate a strong blood oxygen level dependent (BOLD) contrast for functional magnetic resonance imaging (fMRI) (4). Moreover, it has been argued that the length-scale dependence of the iDQC signal might be exploited for an external adjustment of the fMRI sensitivity to blood vessels of different sizes. However, Marques and Bowtell (5) could not produce a significant effect of the correlation distance on the BOLD contrast in numerical simulations of the iDQC signal. A thorough experimental investigation of a potential dependence of fMRI results upon d_c is currently still missing. Goal of the present work was therefore to study the functional contrast obtained with iDQC-based imaging over a relatively wide range of correlation distances and for different evolution times.

Materials and Methods

All experiments were carried out at 3 T (Siemens MAGNETOM Trio). A modified CRAZED sequence with an EPI readout was used to generate a strong gradient-echo type functional iDQC contrast (TR=5 s; TE=70 ms; evolution time τ=15/20 ms; 5 axial slices; voxel size 4×4×5 mm³; bandwidth 65 kHz; refocusing pulse 120°; two-step phase cycle). The correlation gradient was applied in z-direction to maximize the signal intensity. 18 healthy volunteers were investigated using an established visual paradigm (blocked presentation of rotating red letters "L" for 30 s after 30 s of rest) after obtaining informed written consent. The total time of each functional run was 13 min. In each subject, three functional runs with different correlation distances between 60 and 300 µm were acquired in a randomized fashion to account for potential habituation effects. Measurements in three subjects were averaged for each value of d_c. In addition, the dependence of the signal strength on the correlation distance was also investigated in the resting state with identical sequence parameters but 10 averages for improved SNR.

Results and Discussion

Figure 1 shows results of functional experiments obtained with d_c between 60 and 300 µm. All acquisitions show activated voxels, which were well contained in the visual cortex. Both the area of activation and the maximum z-value decreased with decreasing d_c (Fig. 2). Analysis of the resting-state signal (Fig. 3) indicated that the observed trends are partly due to the intrinsic diffusion weighting of the iDQC signal, which changes with the correlation length according to $S/S_\infty = (d_c^2/2D\pi^2 TE)\times[1-\exp(-2D\pi^2 TE/d_c^2)]\times\exp[-D(\Delta_c-T/3)\pi^2/d_c^2]$, where Δ_c is the (diffusion) time between the two gradient lobes of the double-quantum filter and S_∞ is the signal for large d_c (6). The percentage signal change, $\Delta S/S$, slightly increased for smaller correlation distances whereas the functional signal is expected to decrease with decreasing vessel size in conventional gradient-echo BOLD-based fMRI (7). The information derived from the percentage signal change under conditions of functional activation and the dependence of the resting-state signal strength on d_c as shown in Fig. 3 were then combined to obtain estimates of the observed z-scores according to $z\sim(\Delta S/S)\cdot$SNR (8). This procedure yielded only poor correspondence with the experimentally obtained z-scores at short correlation distance as long as a constant noise level independent of the selection of d_c was assumed. However, the resting-state experiments indicated that the suppression of spurious signal fluctuations from unwanted coherence pathways was less efficient at the shortest correlation distances increasing the background noise of the images. The intrinsic SNR thus progressively decreased at smaller correlation lengths leading to a lower statistical power and a reduced number of significantly activated voxels. Upon proper consideration of the noise floor, the computed z-scores were similar to the experimentally observed ones without requiring additional assumptions about a length-scale dependence related to the vessel size.

Conclusion

Consistent indications that the functional contrast in iDQC-based fMRI can be tuned to vessels of a particular size by adjustment of the correlation distance were not obtained for d_c ranging from 60 to 300 µm. By contrast, the observed variation of the functional iDQC signal upon d_c was quantitatively explained by the inherent diffusion weighting of the CRAZED sequence. These results are in keeping with previous numerical simulations of the iDQC signal in inhomogeneous solutions (5).

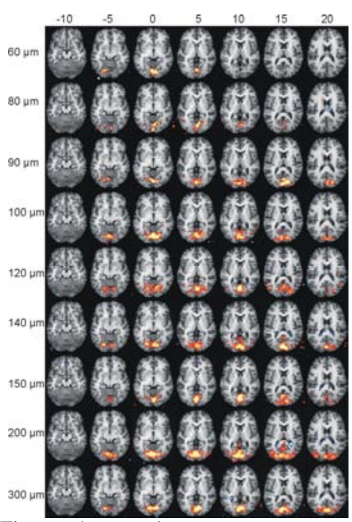

Figure 1. Functional z-maps recorded with different correlation distances (τ=15 ms). The z-coordinate (Talairach system) is given in the top row.

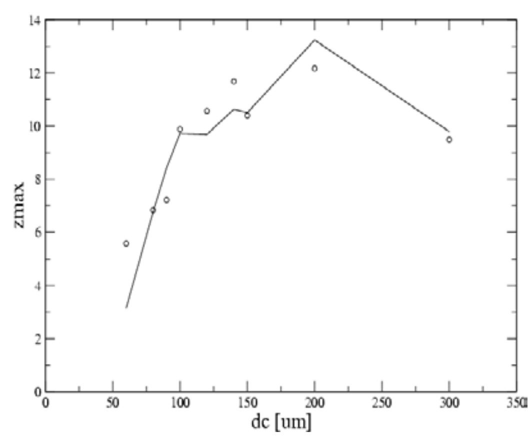

Figure 2. Observed variation of the maximum z-value with d_c (circles) and calculated z-values (solid line) for an evolution time τ=15 ms. The dependence of the background noise on d_c related to a varying degree of suppression of unwanted signal contributions was considered in such calculations.

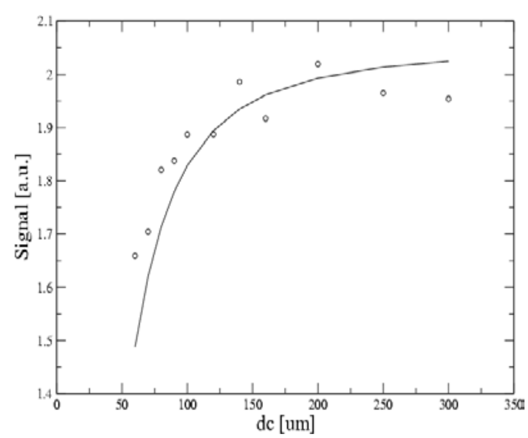

Figure 3. Theoretical variation (solid line) of the iDQC signal strength with the correlation distance and results from the resting-state experiment (circles) for an evolution time τ=15 ms.

References

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