Combined T2*-Weighted Acquisitions of the Human Brain and the Cervical Spinal Cord with a Dynamic Update of the Linear Shims

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Introduction

Important functions of the central nervous system like sensory processing and motor execution involve the spinal cord. So far, fMRI experiments targeting either the spinal cord (e.g. [1-3]) or the human brain have been performed to study e.g., motor, sensory, and pain processing. However, for a direct investigation of the functional interaction of the brain with the spinal cord, combined acquisitions covering both structures in the same experiment are needed. Such fMRI experiments are challenging due to the different, partly counteracting requirements for brain and spinal cord imaging. This not only affects the image resolution and the field-of-view but also the receive coils and the shim adjustment that must provide a sufficient homogeneity of the magnetic field to avoid excessive artifacts. In particular the latter point is hard to realize for the brain and spinal cord simultaneously with a static shim set up. Here, it is shown that combined T2*weighted acquisitions of the brain and the cervical spinal cord are feasible with a reasonable image quality for both regions by (i) using different resolutions, fields-of-view, and slice thicknesses for the slices in the brain and in the spinal cord, respectively, (ii) a dynamic selection of the receive coil with the signal of the head coil only considered for the slices in the brain and the neck coil only for slices in the spinal cord, respectively, and (iii) a dynamic update of the linear shim, i.e. using different values for the brain and the spinal cord region, respectively.

Methods

Measurements were performed on a 3T whole-body MR system (TIM Trio, Siemens Healthcare) using a 12-channel head and 4-channel neck coil (both receive-only). Healthy volunteers were investigated from which informed consent was obtained prior to the examination. The basic geometric setup and echo-planar imaging pulse sequence used in the present study are sketched in Fig. 1. Typically, 40 slices in two stacks (see Fig. 1a) were acquired within a TR of 3.27 s, 32 slices in the brain (field-of-view 224×256 mm^2, resolution 2×2×2 mm^2, gap between slices 1 mm) and 8 slices in the cervical spinal cord (field-of-view 112×128 mm^2, resolution 1×1×5 mm^2, no gap between slices). Dedicated timings were used for the slices in the brain and in the spinal cord (see Fig. 1b) with echo spacings of 0.75 ms and 1.05 ms and bandwidths per pixel of 1502 Hz and 1086 Hz yielding echo times of 30 ms and 38 ms, respectively. A parallel imaging (GRAPPA) [4] acceleration factor of 2 was used for both regions, only measurements performed to demonstrate the influence of the coil sensitivities were obtained with a partial Fourier sampling factor of 6/8 instead. Spatial saturation pulses were used to avoid aliasing artifacts for the spinal cord slices without affecting the brain slices. To improve the signal-to-noise ratio (SNR), the receive coil was dynamically selected using only the head coil for the slices in the brain and only the neck coil for the slices in the spinal cord (see Fig. 1). The adjustment of the linear shim terms was performed for the slice stack in the spinal cord but gradient offsets to all three axes were applied for the slice stack in the brain in order to realize the optimum linear shim terms for the brain slices during their acquisition (see Fig. 1).

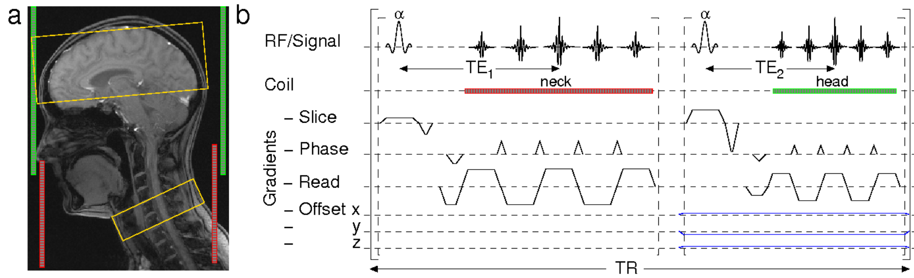

Fig. 1: (a) Example for the geometric setup chosen to cover the brain and cervial spinal cord in a single experiment (red: neck coil, green head coil) and (b) corresponding echo-planar imaging pulse sequence. Different geometries (resolution, field-of-view, slice thickness) and coils were used for the spinal cord (first dashed bracket) and the brain (second dashed bracket). Furthermore, gradient offsets (blue) were applied for the slices in the brain inMR order to realize the linear shim terms required.

Results

The coil sensitivity acquisitions (Fig. 2) reveal that the head and neck coil elements do not contribute significant MR signals to the slices in the cervical spinal cord and the brain, respectively, and vice versa. But they provide additional noise which means that a dynamic selection of the receive coil elements effectively increases the SNR of the acquisitions (Fig. 3). Using only the head coil elements for the slices in the brain increases their SNR by about 10%, selecting only the neck coil for the spinal cord slices yields an SNR improvement of about 80% (see Fig. 3). The advantage of the chosen shimming approach is demonstrated in Fig. 4. Optimizing the shim for the brain slices, yields a non-optimum image quality in the spinal cord, adjusting the shim terms to the spinal cord considerably degrades the brain images. However, updating the linear shim terms for the brain slices dynamically, restores a reasonable image quality in the brain (see Fig. 4). Example images of the brain and the cervical spinal cord that were obtained with a dynamic update of the linear shim terms are presented in Fig. 5.

The results presented demonstrate that the brain and the cervical spinal cord can be covered in a single fMRI experiment which could help to reveal the functional connectivity between them.

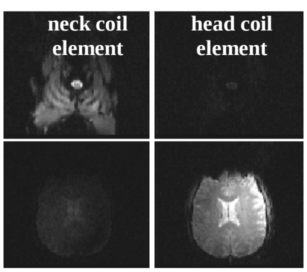

Fig. 2: MR images obtained with only one element of the neck coil (left) and of the head coil (right), respectively. The grey scaling is identical, i.e. the image intensities directly reflect coil sensitivities.

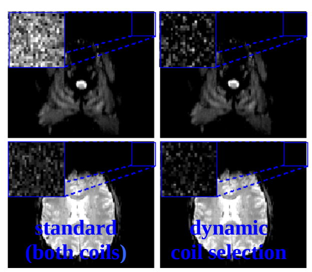

Fig. 3: Images obtained using all coil elements (left) and a dynamic coil selection (right) where only the neck coil for the spinal cord slices and only the head coil for the brain slices. The magnified background noise regions demonstrate the reduced noise intensity yielding an SNR improved by 10% in the brain and 80% in the spinal cord.

References

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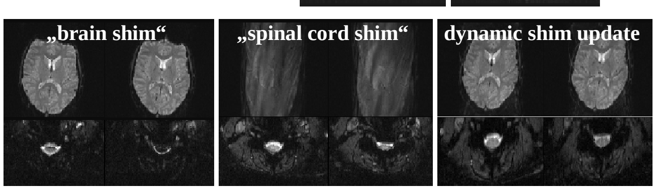

Fig. 4: Brain (upper) and spinal cord images (lower) obtained in a single measurement. The images were acquired with the static shim being optimized for the brain slices (left) or the spinal cord slices (middle) and with the linear shim terms being dynamically updated to the optimum values for the spinal cord and the brain slices, respectively (right).

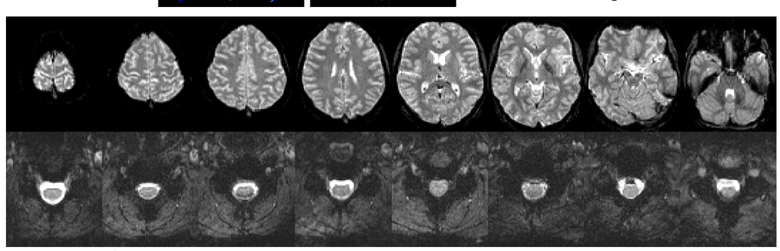

Fig. 5: 16 of 40 slices acquired in the brain (32 slices) and the spinal cord (8 slices) of a healthy volunteer in a single acquisition. The measurement was performed using the dynamic receive coil selection and the dynamic update of the linear shim terms.