BASP Frontiers Workshop 2011

Motion Detection Using FID Navigators

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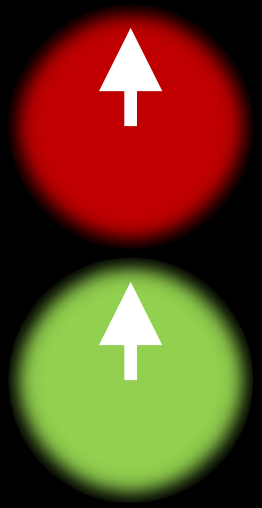
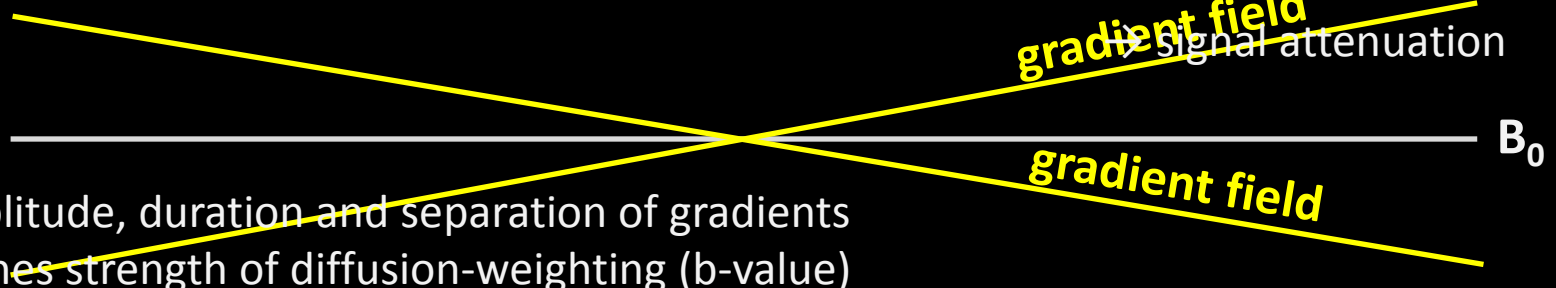
Setting the Stage I - Diffusion Sensitisation

Diffusion is a random walk of molecules in a medium (Brownian motion).

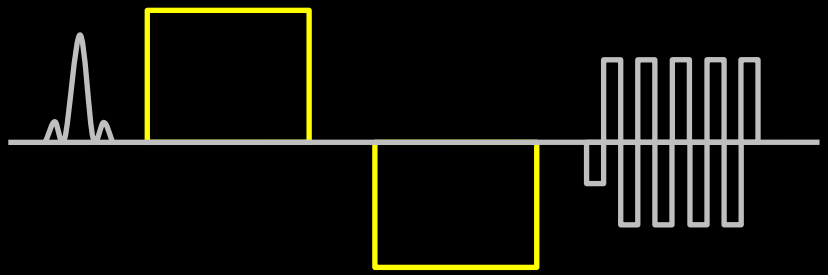


During diffusion sensitisation high motion sensitivity
→ **use single-shot techniques (like EPI)**

Phase difference
→ signal attenuation



Amplitude, duration and separation of gradients
defines strength of diffusion-weighting (b-value)



Setting the Stage II – Multi-Coil Arrays

- Surface coils:
  - good SNR properties
  - but: limited FOV (highest SNR at depth = diametre)
- Solution: Use “NMR Phased Arrays”(Roemer et al. 1990)
  - Roemer referred to ultrasound and radar naming it!
  - Low-impedance preamps and coil overlap to avoid mutual inductance
- Instead of exploiting the increased SNR,
  use spatial coil sensitivities to perform parallel imaging

Setting the Stage III – Navigators in MRI

Navigators use a portion of additional data to derive “other” information (in our case about motion)

- In general, the additional sampling takes time
- Navigators may disturb imaging procedures

Multi-channel coils have been established in MRI

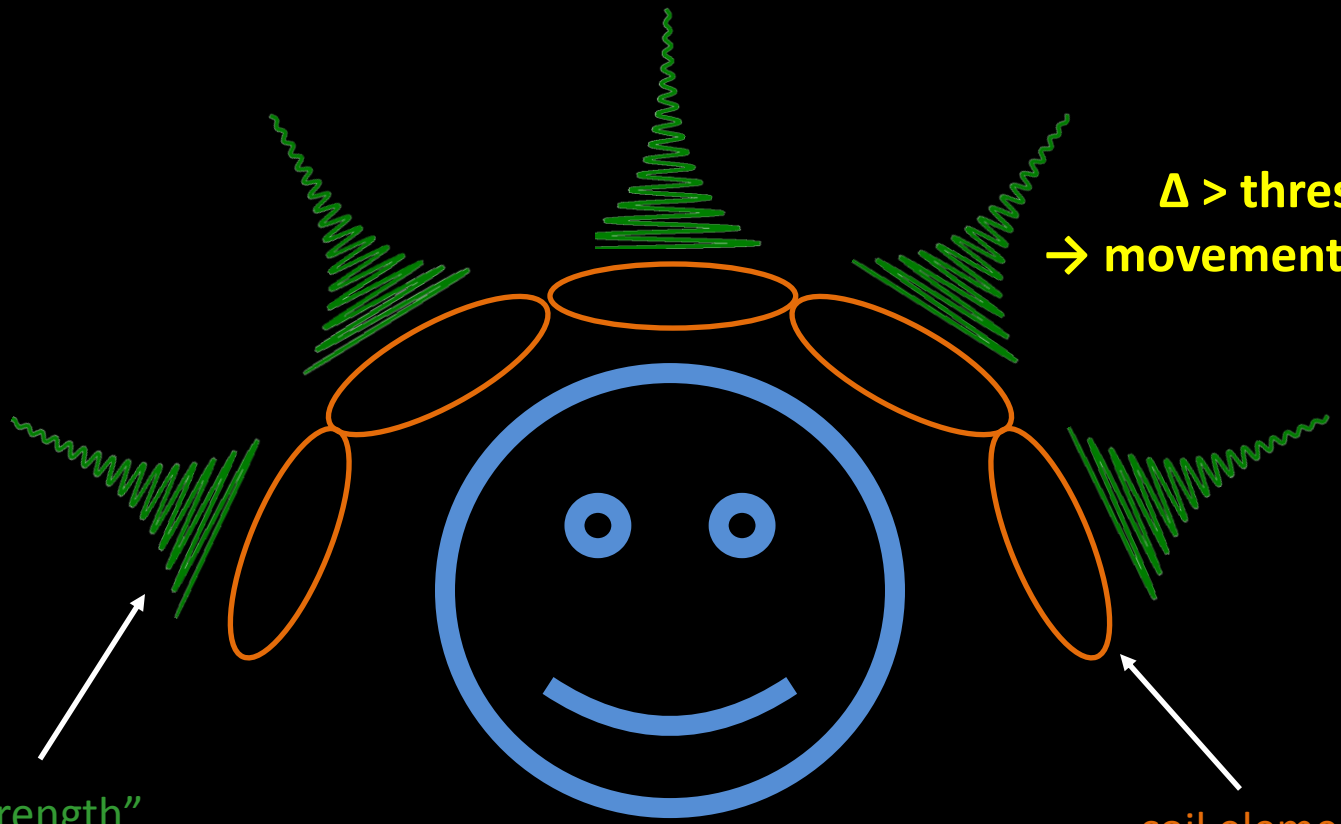
Can one use the properties of multi-channel coils to derive information about motion very swiftly?

→ This novel approach should be general enough to be compatible with many acquisition schemes.

→ Try to minimise the interference with the actual imaging

The Idea of FID Navigators

Both amplitude and phase of the coil elements' MR signals change when object approaches/departs from coil element:



FID = free induction decay
(observable NMR signal after excitation while no gradients etc. are active)

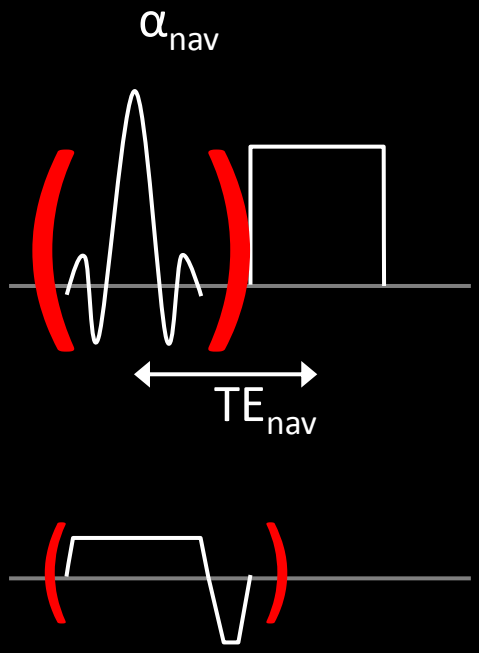
FID Navigators in Detail

Assumption:
Magnitude and phase changes provide information about head movements

Problem:
How to monitor them over the measurement?

Idea:
Repetitive sampling of a short part
(~ 50 µs are enough) of an FID

Realisation:
Either dedicated excitation or squeeze in navigator after host sequence pulse



→ Approach is compatible with many sequences
→ Sampling is very quick

FID Motion Navigators - Challenges

Albeit simple, the FID navigator concept introduced challenges

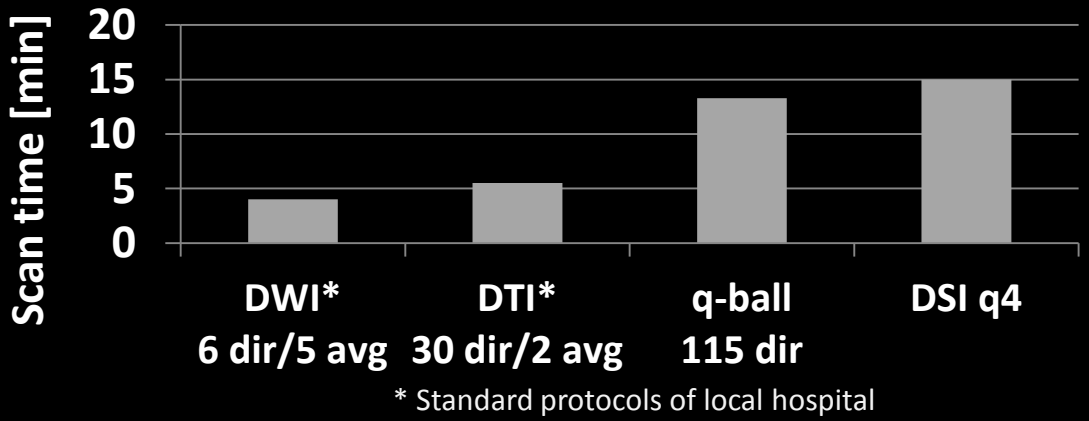
- Cardiac and respiratory activity introduce periodic B_0 shifts
- Other drifts
  - Hardware-induced frequency drifts
  - Thermal effects
- Data from all coil elements have to be considered

  → How to combine them?

  → Real-time constraints for prospective motion detection/correction

Why Motion Correction for Diffusion Imaging?

Today's diffusion sequence of choice: single-shot EPI



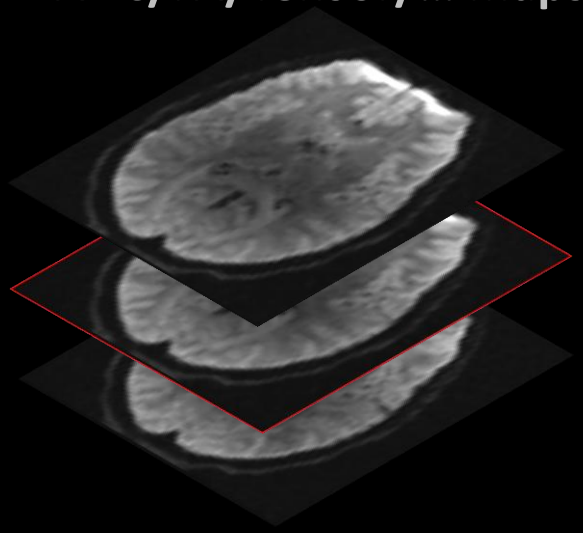
* Standard protocols of local hospital

Long scan times are problematic, especially for

→ children/elderly

→ uncooperative patients

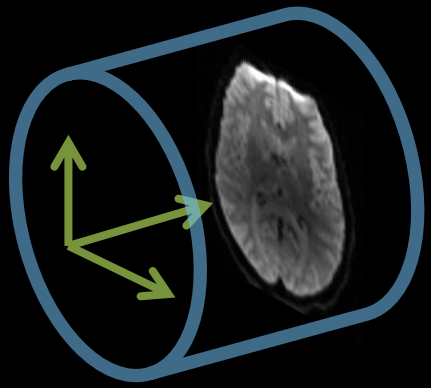
The volumes are combined to ADC/FA/Tensor/… maps



Information is lost in case of bulk motion

Coordinate systems

Diffusion gradients are defined in the scanner coordinate system



Retrospective corrections have to take this into account

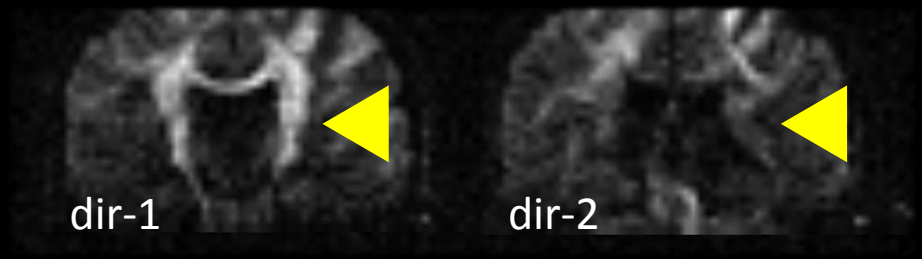
What can we do about it?

- Correct volumes retrospectively
  - Signal dropouts are hard/not possible to correct
  - Interpolation reduces quality
- Use optical/field probe methods
  - Requires external hardware and is difficult in a clinical setup

→ An easy-to-use prospective correction is desirable.

Why not use PACE-like prospective techniques?

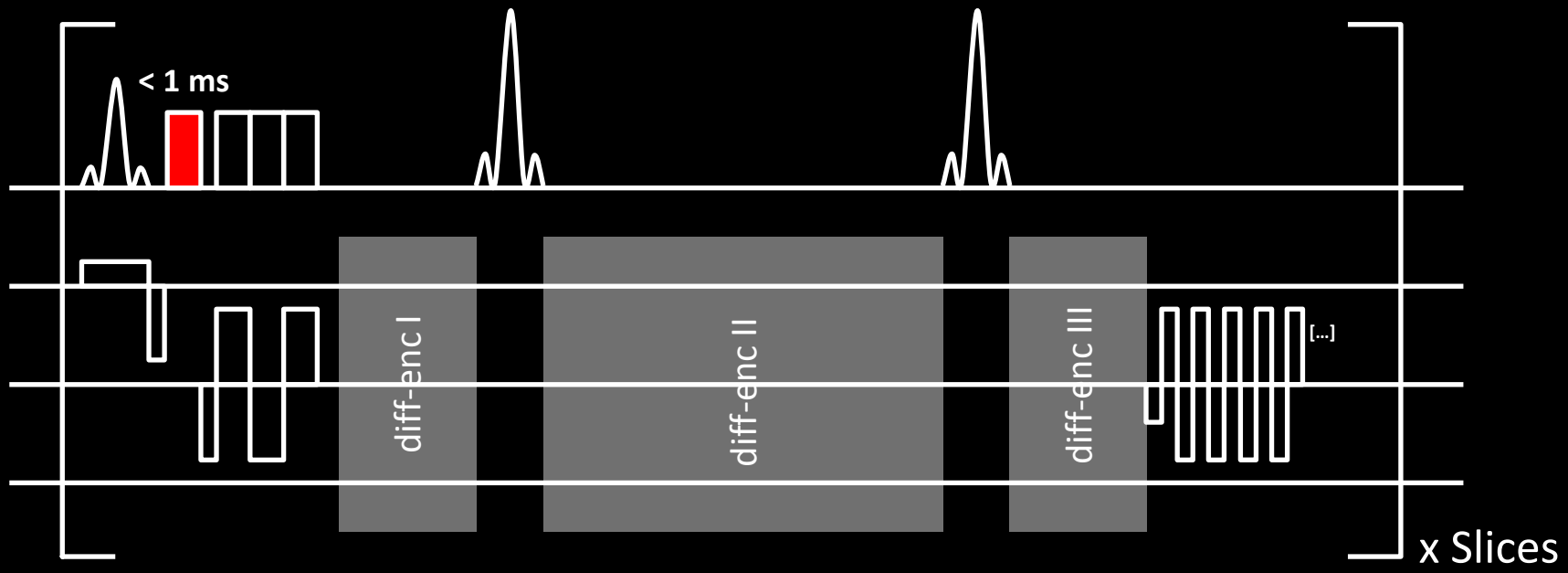
An example: b=3000 s/mm^2



- Image features change considerably between weighting directions
- High noise levels at b > 500 s/mm^2

→ Registration approaches have difficulties/fail for high-b DWI.

FID Navigator added into Diffusion Sequence

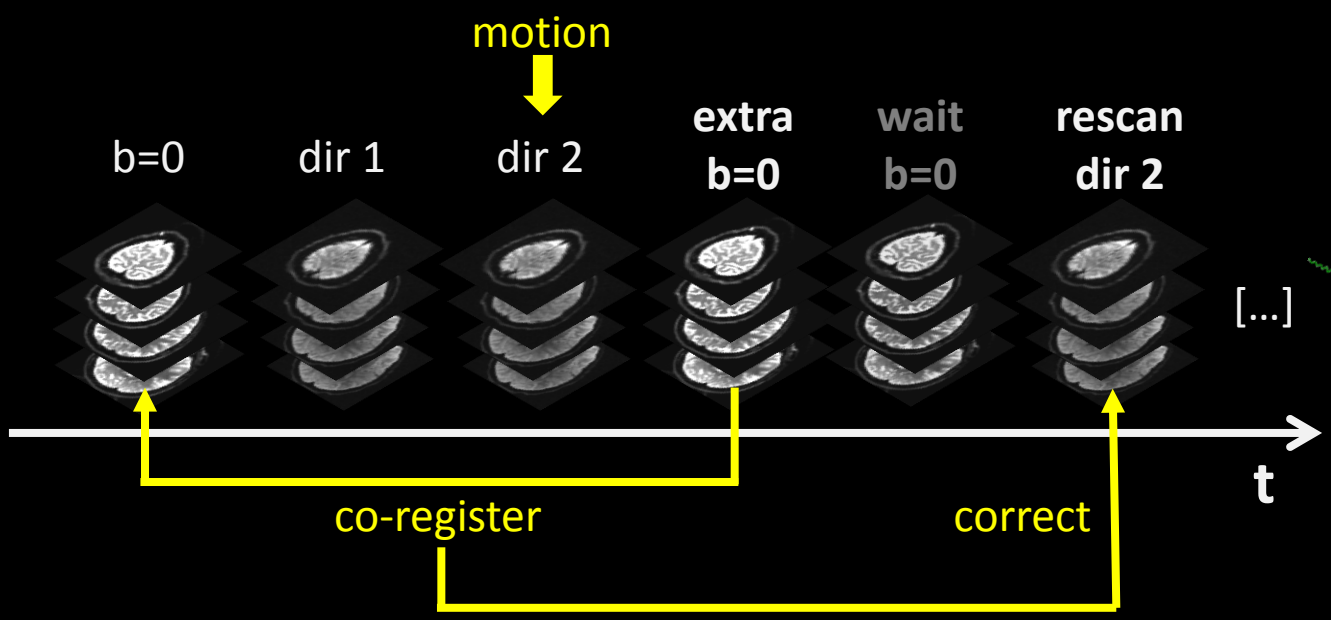


- FID is sampled after each excitation pulse, hence #slices times/volume.
- FIDs from low-energy (empty) slices are not taken into account.
- One FID navigator value per volume is obtained computing the difference to the preceding volume using the heuristic:

$$rd(n) = 100 * \langle\ max_5 \left| \forall s \in UsedSlices, median\left(real\left(\frac{nav_n(s,c) - nav_{n-1}(s,c)}{nav_{n-1}(s,c)} \right) \right) \right| \rangle - rd(2)$$

Prospective Diffusion-MoCo Using FID Navigators

- Use **FID navigator** (< 1 msec) to detect motion as described
- Motion detected → **acquire additional b=0 volume ("extra-b0")**
- **Register** extra-b0 to first b=0 volume
- **Repeat** motion-corrupted volume and go on with the sequence
- If motion occurs, acquisition **time prolongs by 2-3 TRs** (10-15s)



Δ > threshold
→ trigger extra b=0 scan

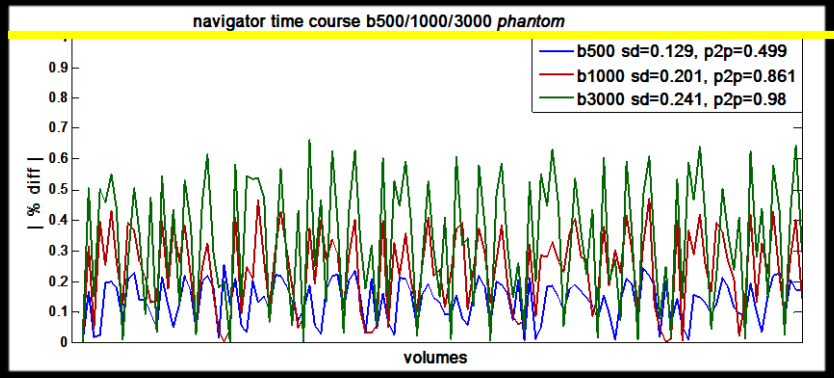
Experimental Design

- Phantom & subjects (N=8) scanned using a 32-channel head coil @ 3 Tesla
- Subjects performed **small, free movements** upon verbal instruction
- **Prospective mode: b=1000**, retrospective mode: b=500 / 1000 / 3000
- Pairs of rest/motion scans:
  Bipolar DW-EPI 12 dir, 5 avg (32 slc x 3mm, 84x84, TR=4.8 s → 5:28 min)

FID-Nav Stability Analysis

Empirical threshold: 1 %

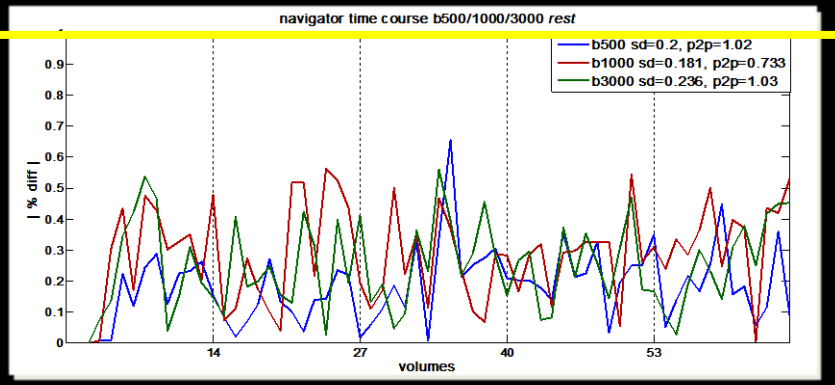
phantom



Mean standard deviation over all phantom experiments

b-val	500	1000	3000
SD [%]	0.14	0.19	0.23

human rest

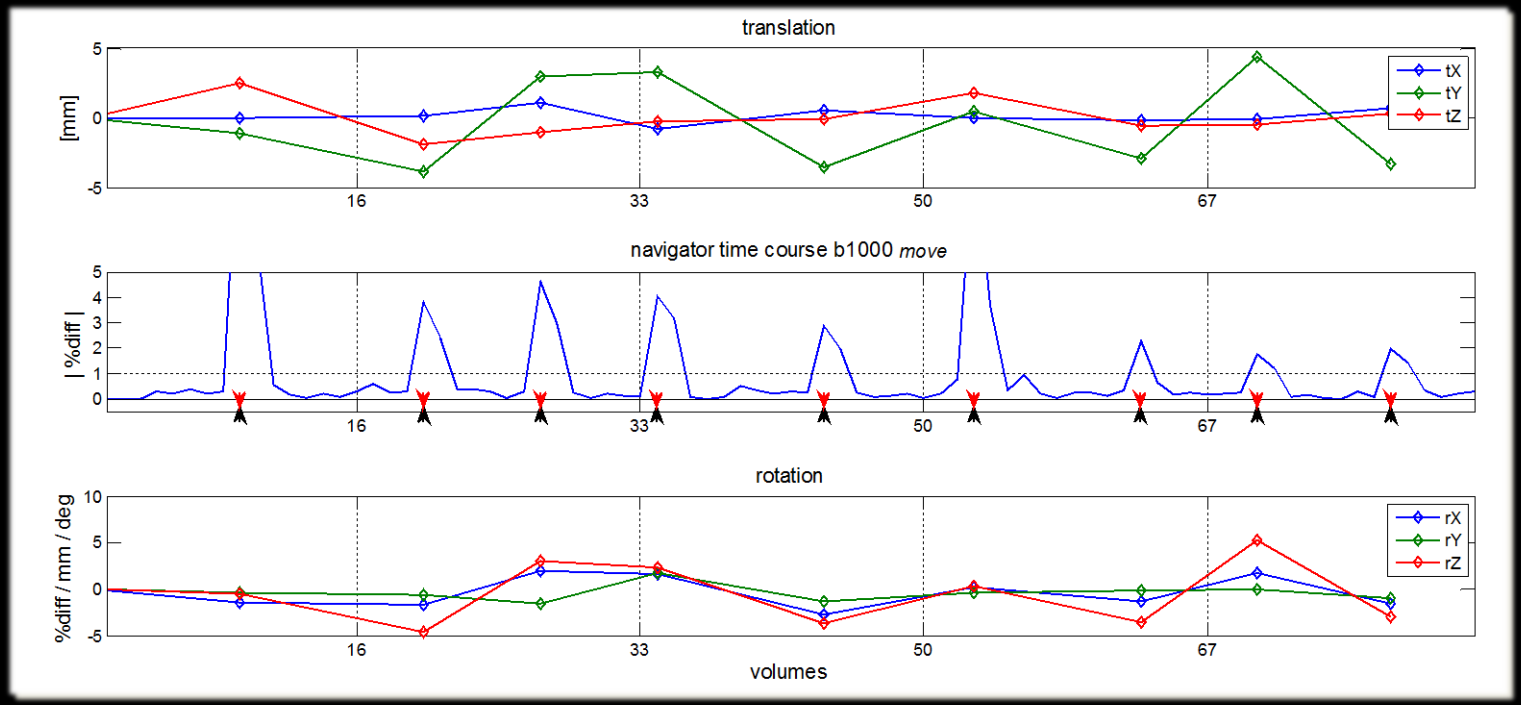


Mean standard deviation over all human rest experiments

b-val	500	1000	3000
SD [%]	0.19	0.20	0.27

Results of Human Experiments

Exemplary time course



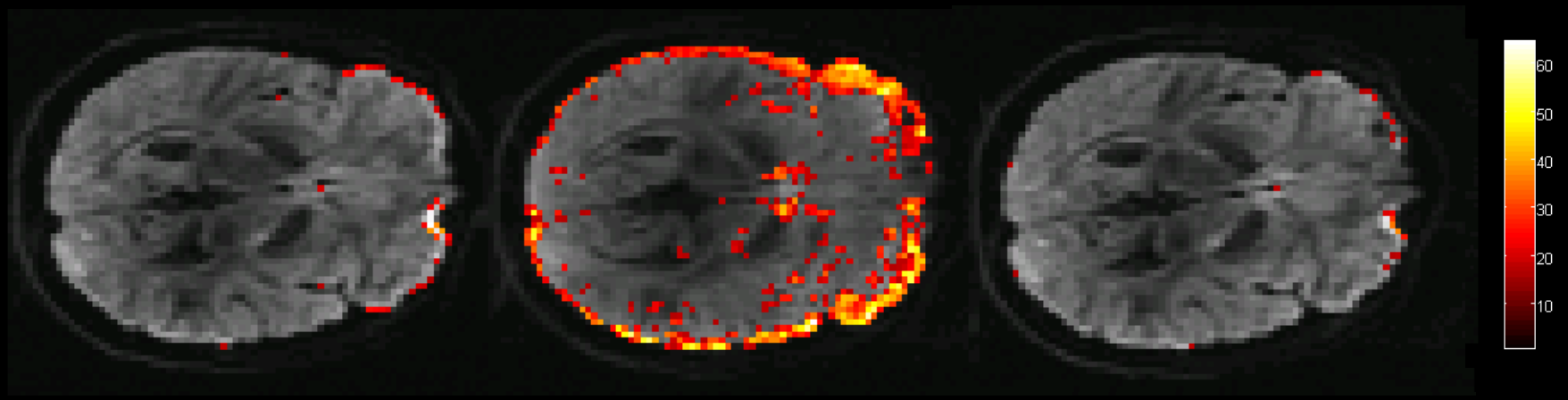
Detection Performance over all Experiments

b-value [s/mm²]	Sensitivity	Specificity
500	92.0 %	99.8 %
1000	94.6 %	99.6 %
3000	93.3 %	98.6 %

Smallest motion detected

Trans [mm]	0.31	0.30	0.24
Rot [deg]	-0.13	-0.14	0.25

Prospectively Corrected Images



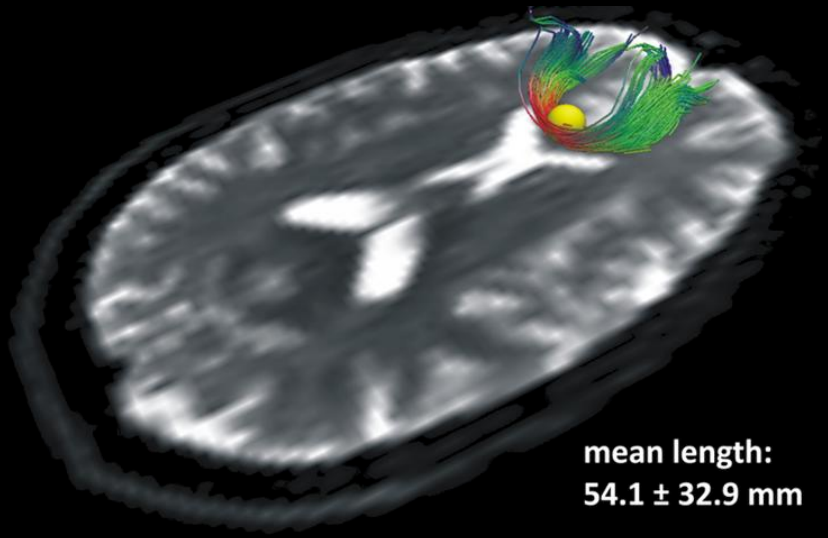
rest **motion** **motion, prospective correction**

Note: Shown data have comparable movements (amplitude and count), but do not stem from the same measurement (3 different, see colours).

- Diffusion information is well preserved.
- In some cases, ghosting is augmented.
- The SD over the 5 averages only increases slightly.
- Registration accuracy expected to be like the “normal” PACE acquisition (algorithm: Thesen et al. 2000, MRM)

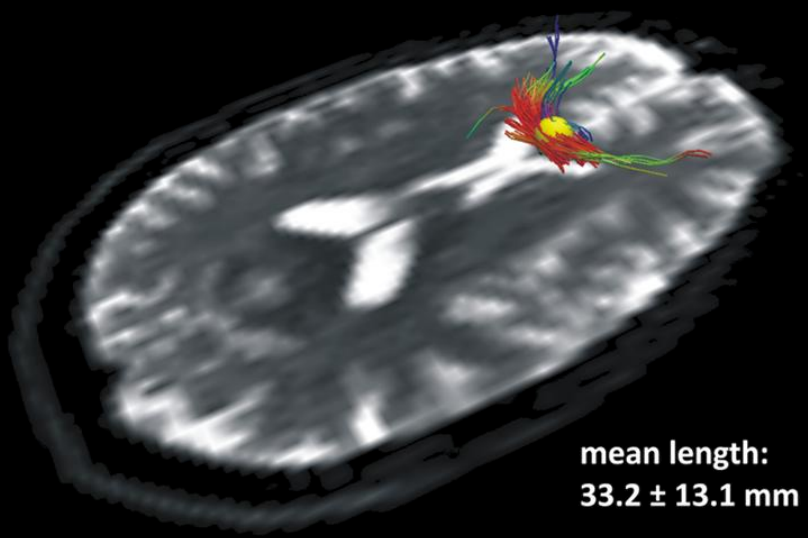
Results Tractography

rest



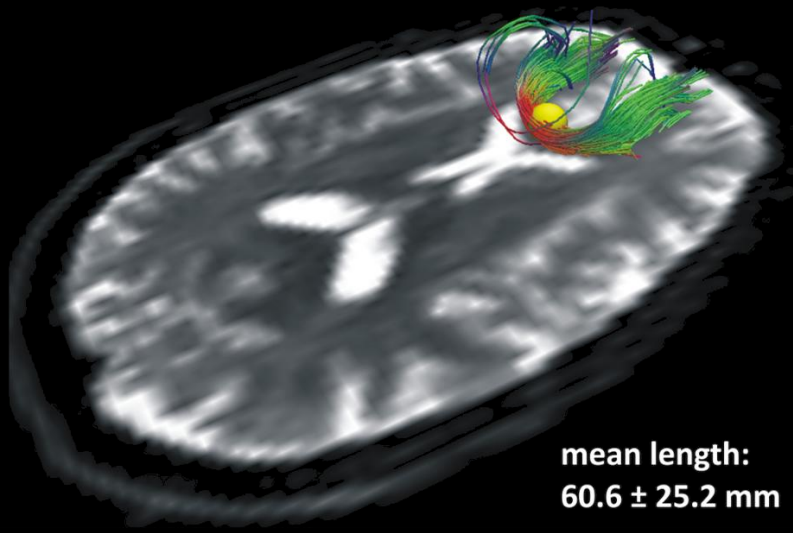
mean length:
54.1 ± 32.9 mm

motion



mean length:
33.2 ± 13.1 mm

motion, prospective correction



mean length:
60.6 ± 25.2 mm

- Tracking of frontal corpus callosum fibres
- Seed point anatomically matched between datasets
- Post-processing using Diffusion Toolkit / TrackVis

Limitations

- Scan prolonged by 2-3 TRs each time a motion is detected.
- Method is so far only tested with a 32-channel coil
- Very slow movements might stay undetected – possible remedies:

  Regularly triggered b0 scan, or adaptation of algorithm.
- Big movements cause large local field variations, changing the local shim.

  But is true for all correction techniques. Dynamic shim methods?
- Tests with very high b-values (up to 8000) yet have to be conducted.

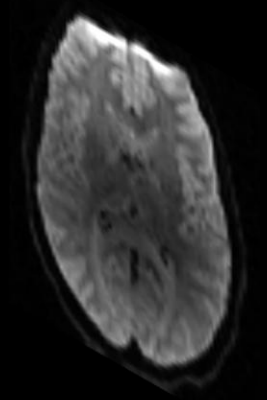
Conclusions

A robust and accurate prospective mo-co method for DW-EPI was established. It maintains diffusion direction consistency and rescans corrupted volumes.

- Exploits the advantageous characteristics of FID navigators
  - No impact on the imaging procedure
  - Negligible time penalty
- Uses a well-proven prospective registration method

It is hoped to improve in particular long DSI/q-ball acquisitions as well as scans with uncooperative or paediatric patients.

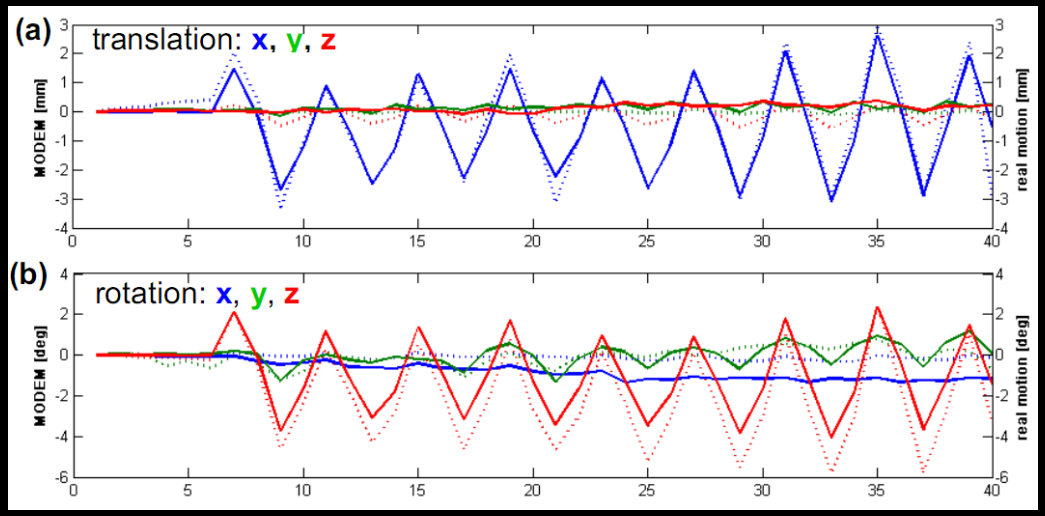
but...



Freezed!

Where we want to go…

Derive motion parameters directly from coil signal changes



Kober et al., ISMRM 2010, abstract #6447

- 3D GRE preparation scan
- Motion simulation using the prep data and coil sensitivity masks
- Obtained matrix [FID(coil) x motion parameter]
- Invert matrix to obtain motion parameter from actual FID signals

Thanks to...

Everybody @ the CIBM Lausanne

Siemens Neuro Team Erlangen

...and you for your attention!

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