Bibliography on Image Registration

Finn Årup Nielsen
CIMBI at DTU Informatics and NRU Rigshospitalet
Lyngby and Copenhagen, Denmark

April 23, 2010

$Revision: 1.115 $
$Date: 2008/07/02 12:26:15 $

Abstract

Reference for image registration are collected. The focus is on image registration for the human brain, particularly for functional neuroimaging. This includes geometrically unwarping of EPIs, intrasubject motion correction, intersubject atlas registration, etc. Pointers to image registration programs are given as well as a list of brain templates.

This structured bibliography is part of a larger collection of bibliographies see http://www.imm.dtu.dk/˜fn/bib/Nielsen2001Bib/. The bibliography is written in LaTeX and BIBTeX and should be available both as HTML and PostScript.

The bibliography is probably far from complete, but new references are added whenever the author finds new material and has the time to add them. You can email the author if corrections are required or you have found references that you fell ought to be included: fn@imm.dtu.dk.

Acknowledgment goes to Mark Jenkinson, Thomas E. Nichols via SPM Extensions, and funding was providing through European Union project MAPAWAMO, International Neuroimaging Consortium (INC) American HBM project, THOR Center for Neuroinformatics, the Villum Kann Rasmussen Foundation and the Lundbeck Foundation.

Contents

List of Tables

1 Keywords

co-registration, image co-registration, image matching, image realignment, image registration, inter-subject registration, linear registration, matching, motion correction, multi-modal image matching, multimodality matching, realignment, registration, registration techniques, resampling, reslicing, rigid matching, robust registration, spatial resampling, spatial interpolation, warping.

2 General references

(Toga, 1998) is an edited volume about brain warping. (Bro-Nielsen, 1996) is a Ph. D. thesis which summarizes some of the methods in operation in 1996. Another is (Maintz and Viergever, 1998).

A general image registration survey is found in (Brown, 1992).

3 Methods

Table 1 display the different types of image transformations or "motion models". These can both be performed in 2D and 3D. *Linear transformation* is only global scaling and rotation, — no translation (when presented in the stadard formulation). With the use of *homogeneous coordinates* translation can be made with a matrix multiplication, thus rigid, similarity and affine transformation can be made with a matrix multiplication. *Shear transformation* can make a parallelogram from a rectangle. Nonlinear warps can have a "symmetric prior" (Ashburner et al., 2000; Ashburner et al., 1999). The transformation can be confined to a specific dimension, e.g., inplane realignment.

Table 2 shows the cost functions associated with image registration. There are several variation of the cost functions:

- Rebinning in mutual information, e.g., 64 (Freire and Mangin, 2001a), or the use of fuzzy membership, smoothing of joint histogram, also called the "grey level cooccurrence matrix" (GLCM).
- Apodization with weighting of the cost function near the edges of the image to avoid local minima (Jenkinson et al., 2002).
- Multigrid optimization where the image registration parameters are first determined on a low-resolution image with large voxel size. The parameters on this first level is used as initial values of the parameters on the next finer level, see, e.g., (Maes et al., 1999)
- Excluding (mask) or weighting voxels differently, e.g., to spatial normalize patients with local lesions (Brett et al., 2001). This functionality is available in the spatial normalization procedure of the SPM2 and FSL package in spm_normalise and flirt, respectively, see Table 7.

Category	Subcategory	Subsubcategory	Description	Reference
Rigid			Only rotation and translation	
Non-rigid	Similarity		Rigid body and global scaling	
—	Affine		Rotation, translation and scaling	
—	Nonlinear	Polynomial basis	E.g., AIR	(Ingvar et al., 1994)
—	—	Cosine basis	E.g., SPM	
—	—	Thin-plate splines		(Bookstein, 1989; Evans et al., 1991; Evans et al., 1994)
—	—	Elastic		(Miller et al., 1993), e.g., FMG
—	—	Fluid		(D'Agostino et al., 2004)
—	—	Nagel-Engelmann		(Nagel and Enkelmann, 1986; Hermosillo et al., 2001)
—	—	Piecewise affine	E.g., Talairach	
—	—	Infinitesimal affine		(Nielsen et al., 2002)

Table 1: Image transformations. Motion models. Restrictions on the motion.

Table 3 shows resampling and interpolation methods. Further references for this step are (Thévenaz et al., 2000; Meijering et al., 2001).

VTK implements affine, "grid" and thin-plate spline transformations with nearest neighboor, trilinear or tricubic interpolation on meshes, regular sampled, structure and unstructured grids http://www.kitware.com, (Gobbi and Peters, 2003).

In Matlab 3D spatial resampling is implemented in the "interp3.m" function with nearest neighbor, linear, cubic and spline interpolation methods.

Type	Subtype	Description	Reference
Point			(Arun et al., 1987)
Point	External fiducial markers		
	Internal landmarks	E.g., “head of caudate” and other matched with Procustes algorithm (least squares)	(Evans et al., 1994), Evans, 1991
—	Robust	Robust alignment with Rayleigh-Bessel function	(Schormann and Dabringhaus, 2001)
Line			
Plane		“Surface Matching Technique”???	(Pellizzari et al., 1989)
Volume			(Collins et al., 1994)
—	Square distance	‘Least square’ or L^2 mismatch	
—	Normalized correlation		
—	Correlation coefficient		
—			
—	Ratio image uniformity	‘Wood’s criteria’	(Woods et al., 1992)
—	Correlation ratio	An asymmetric measure: $\eta(\mathbf{y}\vert\mathbf{x}) = \frac{\mathsf{V}[\mathsf{E}[\mathbf{y}\vert\mathbf{x}]]}{\mathsf{V}[\mathbf{y}]}$	(Roche et al., 1998b; Roche et al., 1998a)
—	Joint entropy		
—	Mutual information	Also refered to as relative entropy	(Collignon et al., 1995; Viola and Wells III, 1995; Wells III et al., 1996; Maes et al., 1997; Studholme et al., 1997)
—	Normalized mutual information		(Studholme et al., 1998)
—	Entropy correlation coefficient		(Maes et al., 1997)
—	With segmentation and *a priori* volumes		(Ashburner et al., 1997)
—	Mutual information to probabilistic tissue class labels		(D’Agostino et al., 2004)

Table 2: Cost functions: Discrepancy and similarity measures. See also (Jenkinson et al., 2002, table 1).

Name	Description	Reference
Nearest neighbor		
Trilinear	Also called ‘linear’	
Cubic		
Spline		
Windowed sinc	Also called ‘truncated sinc’	e.g., (Hill et al., 1994)
Mixed linear/windowed sinc		
Unwindowed sinc		
Chirp-z	Fourier domain analogue of sinc interpolation	(Woods et al., 1999; Rabiner et al., 1969)
Mixed linear/chirp-z		

Table 3: Spatial resampling. Partially from http://bishopw.loni.ucla.edu/AIR3/overview.html

4 Geometric unwarping of EPI

Unwarping of EPI can be approached as an multi-modality non-rigid image registration problem: EPI scans can have geometric and intensity distortions and are to be match with anatomical scans, e.g., a MRI T1 image (Studholme et al., 1999; Studholme et al., 2000). In (Kybic et al., 2000) the deformation field is modeled with splines. (Andersson and Skare, 2002) describes an unwarping algorithm for diffusion weighted EPI.

Other references for unwarping are (Jezzard and Balaban, 1995; Munger et al., 2000). An overview appears in (Hutton et al., 2002)

Name	Method and description	Reference
Field-map undistortion (*)	Undistortion by a field (phase) map	(Cusack and Papadakis, 2002; Cusack et al., 2003), http://www.mrc-cbu.cam.ac.uk-/Imaging/fieldmap_undistort/
FUGUE *	'FMRIB's Utility for Geometrically Unwarping EPIs' Program for EPI unwarping included in FSL	(Jenkinson, 2001), http://www.fmrib.ox.ac.uk/fsl/fugue/
PRELUDE *	Utility program for FUGUE	http://www.fmrib.ox.ac.uk/fsl/fugue/
Unwarp *	Correction of movement-by-susceptibility induced variance	(Andersson, 2001), http://www.fil.ion.ucl.ac.uk/spm-/toolbox/unwarp.html, toolbox for SPM99. Integrated in SPM2.

Table 4: Correction for geometric distortion.

5 Motion correction

In motion correction the brain (and head) is typically regarded as a rigid body where only rotation and translation in space are possible. Introductions to this subject are (Cox, 1996; Brammer, 2001). This type of registration can also be found under names such as PET-PET registration, MRI-MRI registration or MR/MR registration.

Some of the problems associated with motion correction are

- Interpolation errors when reslicing.
- 'Movements at certain frequencies can interact with the physics and temporal dynamics of the image acquisition protocol' (Woods et al., 1999).
- In functional neuroimaging head movements can be correlated with the paradigm (Hajnal et al., 1994; Bullmore et al., 1999). This is also called *task-related motion* or *stimulus correlated motion*. Even submillimeter movement can have an influence (Field et al., 2000; Desmond and Atlas, 2000).
- Applying a non-robust motion correction on data with large activations can produce spurious activations (Freire and Mangin, 2001a; Freire and Mangin, 2001b). This problem becomes more serious with larger MR scanner field strengths (e.g., 3T compared with 1T) as well as larger activation with addition of contrast agents such as MION. Contour-based methods should be less sensitive to the confound (Biswal and Hyde, 1997). A robust algorithm is also describe by (Hsu et al., 2001).
- Differencies in the field of view among the images cause the cost function to have many local mimima (Jenkinson et al., 2002).
- Within scan motion can produce complex confounds that separate slice-timing and realignment procedures cannot fully correct and 4D algorithms are required (Bannister et al., 2002).

A visualization method for the motion artifacts are described in (Lacey et al., 1999; Thacker et al., 1999), see also http://www.tina-vision.net/tina4/tina_tk_fmrimotion.html.

Tools for motion correction of 3D functional neuroimages are presented in table 5. Other motion correction methods are described in (Minoshima et al., 1992; Snyder, 1996; Hill et al., 1994).

Motion correction for list-mode PET is possible with optical tracking systems, e.g., with the POLARIS system (Watabe et al., 2004). A real-time system with real-time image-based motion detection during fMRI scan and subsequent adjustment of slice position is described in (Thesen et al., 2000).

(Ardekani et al., 2001) compared 4 algorithms. Given the range of noise and misalignments imposed the results tended to show the following order (with the most accurate first): SPM99, AFNI98, TRU, AIR.

The motion parameters (and derived parameters) can be included as nuisance parameters in modeling, e.g., in columns of a design matrix of a general linear model (Friston et al., 1996; Lund et al., 2005; Brett, 2005; Johnstone et al., 2005). This can have large impact on the summary image obtained by statistical tests (Lund et al., 2005). (Grootoonk et al., 2000) find that interpolation errors account for the residuals and suggest using sinusoids as the transformation between the movement and the design variables. An application for EEG-fMRI data with patients with epilepsy is described in (Lemieux et al., 2007). This approach included "scan nulling".

In MRI motion correction is usually performed for fMRI, but it might have some utility for structural (anatomical) MRI (sMRI/aMRI) scans as well (Kochunov et al., 2006).

Table 5: Motion realignment tools. A star '*' indicates that the tool is readily available on the Internet.

Name	Description	Reference
AFNI *	Squared distance cost function implemented by the `imreg` and `2dImReg` programs for 2D registration and `3dvolreg` for 3D registration	(Cox, 1996), http://afni.nimh.nih.gov/afni-/AFNI_Help/imreg.html
AIR *		AIR 3 (Woods et al., 1998a), AIR 5: http://bishopw.loni.ucla.edu/AIR5/
DART	An algorithm that operates in the Fourier domain (k-space)	(Maas et al., 1997)
Flirt *	Motion correction using Flirt (McFlirt) Multiresolution optimization with apodization	(Jenkinson et al., 2002; Jenkinson and Smith, 2001; Jenkinson and Smith, 2000; Bannister and Jenkinson, 2001) http://www.fmrib.ox.ac.uk/fsl/flirt/
INRIAlign *	Robust cost function	(Freire et al., 2002; Freire and Mangin, 2001a), http://www-sop.inria.fr/epidaure-/software/INRIAlign/index.html
Reg *	Rigid-body or affine intramodal registration software by Philippe Thévenaz	(Thévenaz and Unser, 1998; Thévenaz et al., 1995; Unser et al., 1993) http://bigwww.epfl.ch/thevenaz/registration/
RS	"Registration software" written as an AVS module with brain surface segmentation and PET-PET and PET-MRI registration	(Alpert et al., 1996)
SPM *	Implemented in the `spm_realign.m` function	(Friston et al., 1995)
TRU *	(Seems to be the same as Thévenez' "reg")	

6 Coregistration

Coregistration or *multimodality image registration* is more complicated than motion alignment since the gray-levels of the tissue types in the different image modality, say PET and MRI, may not correspond to each other.

Early voxel-intensity based algorithms are described in (Woods et al., 1993; Ardekani et al., 1995; Andersson et al., 1995). Table 6 displays coregistration tools. Note that most image registration software that include some form of the mutual information will be able to do co-registration.

Table 6: Coregistration tools. A star '*' denotes that the tool is easy available.

Name	Transform	Description	Reference
AIR *		`alignlinear` in AIR3.0	(Woods et al., 1993) http://www.loni.ucla.edu/NCRR/-Software/AIR.html
AMIR			(Ardekani et al., 1995)
CBA		Commercial program from *Applied Medical Imaging*	http://www.appmed.se
Flirt *			(Jenkinson et al., 2002; Jenkinson and Smith, 2001; Jenkinson and Smith, 2000) http://www.fmrib.ox.ac.uk-/fsl/flirt/
IIO	Rigid	"Interative Image overlay". Manual alignment.	(Willendrup et al., 2004)
IPS	Rotation/-translation	"Interactive Point Selection". Semi-automated landmark-based with least-squares optimization, applied for neuroreceptor studies. Part of the MARS (Multiple Algorithms for Registration of Scans) package.	(Willendrup et al., 2002a; Willendrup et al., 2002b; Willendrup et al., 2004), http://www.nru.dk/people-/willend/mars/
MATCH	Non-linear		(Hermosillo et al., 2002; Chef d'Hotel et al., 2002; Hermosillo et al., 2001). Used for co-registration in, e.g., (Fize et al., 2003)
MIPAV *	Linear, thin plate spline	Landmark-based least-squares fitteing	(Arun et al., 1987), http://mipav.cit.nih.gov/
MIRIT		Commercial coregistration program based on mutual information	(Maes et al., 1997), http://bilbo.esat.kuleuven.ac.be-/web-pages/downloads/Mirit-/Mirit.html
MPI (?)		Interactive tool	(Pietrzyk et al., 1994)
MRIWarp *	Non-linear	General registration with mutual information and correlation coefficient (and least squares) cost function	(Kjems et al., 1999a; Kjems, 1998; Kjems et al., 1999b) http://hendrix.imm.dtu.dk-/software/mriwarp/
RS		"Registration software" written as an AVS module with brain surface segmentation and PET-PET and PET-MRI registration	(Alpert et al., 1996)

Name	Transform	Description	Reference
RView8	Rigid	(mmvreg/rview)	http://noodle.med.yale.edu/˜cs-/software/software.html
SPM *		Both mutual information registration and registration based on WM/GM/CSF segmented images are implemented (in SPM99). SPM2 incorporates a number of different cost functions related to mutual information (The "Coregister" button and the `spm_coreg.m` function)	(Ashburner and Friston, 1997; Ashburner et al., 1997; Collignon et al., 1995; Wells III et al., 1996; Maes et al., 1997; Studholme et al., 1998), http://www.fil.ion.ucl.ac.uk/spm/

IPS, IIO, AIR 5.0 and SPM99 are compared on MRI to FDG-PET and altanserin-PET coregistration in (Willendrup et al., 2004). SPM99 and AIR are found to perform between on simulated FDG-PET-to-MRI co-registration than the manual methods of IPS and IIO. With the altanserin radiotracer, where there it finds little or no 5HT2A binding in cerebellum, the manual methods perform better.

Another comparison of co-registration algorithms appears in (Pfluger et al., 2000).

7 Spatial normalization

Discussion of the origins of spatial normalization appears in (Fox, 1995). Early reference to spatial normalization are (Fox et al., 1985; Friston et al., 1989). Other names are *inter-subject brain image registration*, *intersubject registration*, *atlas warping*, ...

In functional neuroimaging spatial normalization insures that the functional results can be compared to the anatomy in multiple subject studies. In (Poldrack and Devlin, 2007) the issues of reporting the functional activation with respect to the anatomy is discussed.

Table 7 lists tools for spatial normalization, while further spatial normalization methods are described in (Bajcsy et al., 1983; Bajcsy and Kovacic, 1989; Gee et al., 1993; Kosugi et al., 1993; Minoshima et al., 1994; Davatzikos, 1996; Christensen et al., 1997; Kochunov et al., 2000; Thévenaz and Unser, 2000). (Andersson and Thurfjell, 1997) report a system for intra and intersubject PET registration (perhaps it is used in the CBA program?). (Thompson et al., 1997) describe a fluid deformation for cortical surfaces. A method for "inter-mouse" warping is described in (Falangola et al., 2005).

7.1 Comparison and evaluations

Talairach normalization has been found to result in a "sulcal variation zone" of 1.5–2.0 centimeters measured against landmarks (Steinmetz et al., 1990). For the medial temporal lobe standard deviation on landmarks have been found to be one or three millimeter, depending on optimal or suboptimal parameters in non-linear basis-based spatial normalization (Salmond et al., 2002), see also (Ramsøy, 2007, appendix 3). The problems associated with spatial normalization of the hippocampus have been discussed in (Krishnan et al., 2006). AFNI, SPM99 and ART have been compared in (Ardekani et al., 2004).

The effect of different spatial normalization (affine AIR, MRIWarp) is evaluated on functional O-15 positron emission tomograhy (PET) data in (Kjems et al., 1999a) with canonical variate analysis, and the study finds that the non-linear MRIWarp procedure is superior to the affine.

An elastic warping is compared to and affine transformation and an SPM96 registration in (Gee et al., 1997), and it finds peak activation from an analysis of functional images higher for the warping than for the affine procedure.

In (Davatzikos et al., 2001b) MR-MR SPM96, PET-PET SPM95, MR-MR SPM99 and STAR are compared and it is found the STAR results in the lowest P-values.

The influence of the template has been investigated with the four choices using SPM99 for spatial normalization of PET FDG images (Gisbert et al., 2003): One choice with the default H20 template provided by SPM and two choices with a constructed FDG templates. One FDG template was constructed from the subjects by averaging spatial normalized FDG PET images that was normalized to the default SPM template, and another FDG template that was constructed by averaging FDG images whose deformation was estimated from MRI images. The last choice did not construct an FDG template and instead warped the subject PET-scans based on deformations estimated from the MRI images. A reported maximum z-score ranged from 4.13 to 4.60.

Table 7: Spatial normalization algorithms and software. A star ("*") indicates that a public program is available.

Name	Description	Reference
AIR3 *		(Woods et al., 1998b; Woods et al., 1999) http://bishopw.loni.ucla.edu/AIR3/
ANIMAL	Also called MNI_ANIMAL. Non-linear registration. First step is similar to AutoReg. Second step uses a deformation field	(Collins et al., 1995), http://www.bic.mni.mcgill.ca-/users/louis/MNI_ANIMAL_home/readme-/readme.html
ART	Many-parameters algorithm	(Ardekani, 2003; Ardekani et al., 2004)

Name	Description	Reference
AutoReg	Also called MNI_AutoReg. Linear transformation with a cross-correlation cost function	(Collins et al., 1994), http://www.bic.mni.mcgill.ca-/users/louis/MNI_AUTOREG_home/readme/
CBA	Translation, scaling, rotation and second transformation	(Greitz et al., 1991; Ingvar et al., 1994)
CHSN *	"Convex Hull Spatial Normalization"	(Lancaster et al., 1999; Downs et al., 1994) http://ric.uthscsa.edu-/projects/chsn/chsn.html
DARTEL *	Diffeomorphic image registration	(Ashburner, 2007), ftp://ftp.fil.ion.ucl.ac.uk-/spm/spm5_updates
FMG	Elastic	(Schormann and Zilles, 1998; Schormann et al., 1996), Email Thorsten Schormann.
HAMMER *	Elastic	(Shen and Davatzikos, 2002; Shen and Davatzikos, 2003; Davatzikos et al., 2001a), https://www.rad.upenn.edu/sbia/software-/index.html#hammer
HBA (*)	"Human Brain Atlas". Linear and nonlinear image registration and template	(Roland et al., 1994) http://www.dhbr.neuro.ki.se/Hba/
LIPSIA (*)	Linear and nonlinear normalization in the LIPSIA package	(Lohmann et al., 2001; Thirion, 1998)
MRIWarp *	Non-linear warp	(Kjems et al., 1999a; Kjems, 1998; Kjems et al., 1999b) http://hendrix.imm.dtu.dk-/software/mriwarp/
SN	9-parameter affine transformation	(Lancaster et al., 1995) http://ric.uthscsa.edu-/projects/spatialnormalization.html
SPM *	Default is a $7 \times 8 \times 7$ basis function in SPM99. SPM2 includes functionality to weight/mask voxels.	(Friston et al., 1995; Ashburner and Friston, 1996; Ashburner and Friston, 1999), http://www.fil.ion.ucl.ac.uk/spm/
STAR	Elastic warping	(Davatzikos, 1997)

7.2 Brain templates

A large part of the spatial normalization algorithms require a target to match to: a *template* — aka. "anatomical textbook", cf. (Miller et al., 1993)). A number of the templates for the human brain is listed in table 8. Further templates/brain atlases are pointed to in (Toga and Thompson, 2000). There is a discrepancy between the Talairach and the MNI templates, and a piecewise affine transformation between the two has been suggested (Brett, 2002). This does not fully compensate (Chau and McIntosh, 2005; Lancaster et al., 2007; Lancaster et al., 2006).

According to John Ashburner an O-15 H2O template can be used to normalize FDG PET image without "disastrous" results SPM mailing list 2002-01-21.

Table 8: Templates: Some of the standard human brains used in stereotaxic alignment.

Name	Age	Modality	Description	Reference
colin27	Adult	T1	MNI single subject (Colin Holmes). Also used in BrainWeb and the default template in SPM96. (Approximately?) in the same space as MNI305 Also distributed with MRIcro as ch2.	(Holmes et al., 1998), SPM99 spm_templates.man. http://www.mrc-cbu.cam.ac.uk/Imaging/-Common/downloads/Colin/.
MNI	Adult	T1, T2, PD, EPI, PET, SPECT	Name for the MNI* templates	
MNI152	Adult	T1, T2, PD	Standard templates in SPM99, distributed volume are smooth with 8mm FWHM in 2mm resolution	SPM99 spm_templates.man
MNI305	Adult	T1	ICBM standard, also distributed in SPM99	SPM99 spm_templates.man, (Collins et al., 1994; Evans et al., 1993; Collins, 1994), ftp://ftp.bic.mni.mcgill.ca-/pub /avgbrain/
'Woods 1999'	Adult	T1, T2 EPI	Based on ten subjects in Talairach scaled space	(Woods et al., 1999)
Visible Human	Adult		Brain from the Visible Human Project	http://www.nlm.nih.gov/-research/visible/-visible_human.html
VAPET	Adult		Used at the VA Medical Center, Minneapolis	
CBA		Cryosections	'Computerized brain atlas', Dept. Neuroradiology, Karolinska Institute. Included in the CBA program Also called "Greitz space".	(Greitz et al., 1991; Seitz et al., 1990; Thurfjell et al., 1995)
HBA			'Human Brain Atlas' from Karolinska Institutet	(Roland et al., 1994)
ECHBA			New HBA. Re-acquired HBA used in European Computerised Human Brain Database	(Schormann et al., 1999; Roland et al., 1999)
'BIT'			Warped single subject	(Lancaster et al., 2001)
EVA833	Elderly		Based on 833 elderly subjects	(Quinton et al., 1999)
—		Ligand PET	[carbonyl-11C]WAY-100635, [11C]raclopride	(Meyer et al., 1999)
—	Adults(?)	PET L-DOPA	Based on 12 subjects	Andreas Meyer-Lindenberg, SPM mailing list 2001-11-20

Name	Age	Modality	Description	Reference
CCHMC	Children	T1	Template based on 148 children age 5–18.	http://www.irc.chmcc.org-/chips.htm, Marko Wilke, http://www.irc.chmcc.org, SPM mailing list 2001-12-17
PAN	—	External measurements	Preauricular-nasion Used in EEG. Not a template. Coordinates defined on individual basis.	
SUIT	Adult		Cerebellum	(Diedrichsen, 2006), http://www.bangor.ac.uk-/˜pss412/imaging/suit.htm
Talairach	(Elderly)	Drawings	Original Talairach images. No MRI exists.	(Talairach and Tournoux, 1988)
Schmahmann	Adult	Drawings, JPG, (T1)	Book with images of cerebellum from colin27	(Holmes et al., 1998; Schmahmann et al., 2000; Schmahmann et al., 1999; Schmahmann et al., 1996; Makris et al., 1996)

7.2.1 Animal brain templates

(Horsley and Clarke, 1908) describe a stereotaxic space for the macaque defined from measurements on Macaca mulatta (Macacus rhesus) and a few cases of Macaca fascicularis (Macacus cynomolgus).

Name	Species	Modality	Description	Reference
B2K	Baboon	T1 MPRAGE, O15-Water PET		(Black et al., 2001b), http://www.nil.wustl.edu-/labs/kevin/ni/b2k/
N2K	Macaca Nemestrina (pig-tailed macaque)	T1, PET		(Black et al., 2001a), http://www.nil.wustl.edu-/labs/kevin/ni/n2k/p1.htm
'Pig space'	Pig (Göttingen minipig$^{\mathrm{TM}}$)	MRI		(Andersen et al., 2001), SPM Mailing list, 2001-8-2
Ratlas	Rat	MRI		(Schweinhardt et al., 2003), http://mr.imaging-ks.nu/expmr.htm
(Rat)	Rat			(Schwarz et al., 2006)
Template Atlas	Macaca fascicularis	Drawings	Bicommisural coordinate system with zero at anterior commissure	http://www.elsevier.com-/homepage/sah/pbm/

Table 9: Animal templates. See http://www.kopfinstruments.com/Atlas/ for a list of animal brain atlases.

(Erwin et al., 1999) describes a functional atlas for the monkey lateral geniculate nucleus with respect to directions in visual space. This is available as "Atlas of a Rhesus Lateral Geniculate Nucleus (LGN)" from http://soma.npa.uiuc.edu/labs/malpeli/atlas/.

7.2.2 Conversion

From 'Template Atlas' (TA) to (Szabo and Cowan, 1984) (SC)

$$\mathrm{AP}_{\mathrm{SC}} = \mathrm{AP}_{\mathrm{TA}} + 17\mathrm{mm}, \tag{1}$$
$$\mathrm{DV}_{\mathrm{SC}} = \mathrm{DV}_{\mathrm{TA}} + 4\mathrm{mm}, \tag{2}$$

and from 'Template atlas' to (Shantha et al., 1968) (SMB)

$$\mathrm{AP}_{\mathrm{SMB}} = \mathrm{AP}_{\mathrm{TA}} + 17\mathrm{mm}, \tag{3}$$
$$\mathrm{DV}_{\mathrm{SMB}} = \mathrm{DV}_{\mathrm{TA}} + 8\mathrm{mm}. \tag{4}$$

These transformations were taken from http://www.elsevier.com/homepage/sah/pbm/atlas/Tempindex.html.

8 Validation and comparison

Type	Description	Reference
Spatial normalization	HBA, SPM(96) and "linear" compared on PET	(Sugiura et al., 1997), (Sugiura et al., 1999)?
MRI/PET coregistration	AIR and SPM(96) compared	(Kiebel et al., 1997b; Kiebel et al., 1997a)
CT, MR, PET coregistration	Internet-based blinded evaluation of 8 algorithms	(West et al., 1997), http://www.vuse.vanderbilt.edu-/~image/registration/
Spatial normalization	Comparison of an affine (AIR), a polynomial (AIR), an cosine (SPM) and a elastic deformation (FMG)	(Crivello et al., 2002)
Spatial normalization		(Hellier et al., 2001; Hellier et al., 2002; Hellier et al., 2003)

Table 10: Validation

A list of validation studies are available in table 10. A comparison of early image registration algorithms appears in (Strother et al., 1994).

In "The Retrospective Registration Evaluation Project" (West et al., 1997; Fitzpatrick et al., 1998) a number of algorithms for CT-MR and PET-MR image registration has been evaluated and the results are available on the Internet from http://www.vuse.vanderbilt.edu/~image/registration/

9 Application

9.1 Image-guided neurosurgery

Uses of spatial normalization in image-guided neurosurgery (IGNS): (Nowinski et al., 2000; Nowinski et al., 1998). (St-Jean et al., 1998) use a deformable version of the Schaltenbrand and Wahren atlas for the basal ganglia and thalamus. Database construction: (Finnis et al., 2000).

9.2 Morphometric analysis

Bookstein, 1996, Biometrics, biomathematics and the morphometric synthesis

10 Unclassified references

- Review (Viergever et al., 1997).
- Petra van den Elsen, Utrecht, 1994 - cross-correlation
- Derek Hill and Dave Hawkes, London, 1994 - moments of joint probability distribution
- Co-registration of cortical magnetic stimulation and functional magnetic resonance imaging Eric P. Bastings, H. Donald Gage, Jason P. Greenberg, Greg Hammond, Luis Hernandez, Peter Santago, Craig A. Hamilton, Dixon M. Moody, Krish D. Singh, Peter E. Ricci, Tim P. Pons, David C. Good, NeuroReport p 1697
- MRreg, Louis Lemieux http://www.erg.ion.ucl.ac.uk/mrreg.html
- F. L. Bookstein (1997). "Landmark Methods for Forms Without Landmarks: Morphometrics of Group Differences in Outline Shape" Medical Image Analysis 1(3):225-243
- U. Pietrzyk and K. Kerholtz and G. Fink et at. An interactive technique for three-dimensional image registration: validation with PET. J. Nucl Med 1994, 35:2011-2018
- Ayache, N.; Boissonat, J.-D.; Brunet, E.; Cohen, L.; Chièze, J.P.; Geiger, B.; Monga, O.; Roccisani, J.M.; Sander, P. Building highly structured volume representation in 3D medical images. Computer Aided Radiology. 89:765-772. 1989.
- ALIGN, http://www.ece.drexel.edu/ICVC/Align/align11.html Multidimensional Alignment Using the Euclidean Distance Transform by Dorota Kozinska, Oleh J. Tretiak, Jonathan Nissanov, and Cengizhan Ozturk Accepted in Computer Graphics and Image Processing.
- http://white.stanford.edu:80/~heeger/registration.html: Multiscale affine and rigid body image registration software in Matlab.
- Pascal Cachier
- Intraoperative brain deformation (brain shift): Medical Image Analysis Volume 6, Issue 4, December 2002, Pages 361-373 Model-driven brain shift compensation Oskar Skrinjar, Arya Nabavib and James Duncanc http://www.sciencedirect.com/science/article/B6W6Y-45PTS3C-1/1/2469e09a8c7060205ca9c0b15f1390b0

References

Alpert, N. M., Berdichevsky, D., Levin, Z., Morris, E. D., and Fischman, A. J. (1996). Improved methods for image registration. *NeuroImage*, 3(1):10–18. PMID: 9345471. DOI: 10.1006/nimg.1996.0002. http://www.sciencedirect.com/science/article/B6WNP-45MGVJH-2F/2/c237c807d538653611a4470ea8492327.

Andersen, F., Rodell, A. B., Danielsen, E. H., Gjedde, A., and Cumming, P. (2001). Automatic registration of 3D-MR volumetric pig brain data into stereotactic standard coordinates (pig space). *NeuroImage*, 13(6):S1295.

Andersson, J. L. R. (2001). Modeling geometric deformations in EPI time series. *NeuroImage*, 13(5):903–919. PMID: 11304086. http://www.fil.ion.ucl.ac.uk/spm/papers/Unwarp/Unwarp.pdf.

Andersson, J. L. R. and Skare, S. (2002). A model-based method for retrospective correction of geometric distortions in diffusion-weighted EPI. *NeuroImage*, 16:177–199. http://www.idealibrary.com/links/doi/10.1006/nimg.2001.1039.

Andersson, J. L. R., Sundin, A., and Valind, S. (1995). A method for coregistration of PET and MR brain images. *Journal of Nuclear Medicine*, 36(7):1307–1315. PMID: 7790961.

Andersson, J. L. R. and Thurfjell, L. (1997). Implementation and validation of a fully automatic system for intra- and interindividual registration of PET brain scans. *Journal of Computer Assisted Tomography*, 21(1):136–144. PMID: 9022786.

Ardekani, B., Braun, M., Hutton, B. F., Kanno, I., and Iida, H. (1995). A fully automatic multimodality image registration algorithm. *Journal of Computer Assisted Tomography*, 19(4):615–623. PMID: 7622696.

Ardekani, B. A. (2003). An improved method for intersubject registration in 3D volumetric brain MRI. In *World Congress on Medical Physics and Biomedical Engineering*.

Ardekani, B. A., Bachman, A. H., and Helpern, J. A. (2001). A quantitative comparison of motion detection algorithms in fMRI. *Magnetic Resonance Imaging*, 19(7):959–963. PMID: 11595367. http://claymore.rfmh.org/~ardekani/papers/ardekani01.pdf. Comparison of four motion realignment algorithms: TRU, SPM99, AFNI98 and AIR. All could provide subvoxel precision and most submillimeter precision. Within the range of noise and initial misalignment impose the results showed that SPM99 and AFNI98 tended to be the best followed by TRU and finally AIR.

Ardekani, B. A., Bachman, A. H., Strother, S. C., Fujibayashi, Y., and Yonekura, Y. (2004). Impact of inter-subject image registration on group analysis of fMRI data. In Iida, H., Shah, N. J., Hayashi, T., and Watabe, H., editors, *Quantification in Biomedical Imaging with PET and MRI: Proceedings of the International Workshop on Quantification in Biomedical Imaging with PET and MRI held in Osaka, Japan, between 26 and 27 January 2004*, volume 1265 of *International Congress Series*, pages 49–59. Elsevier, Amsterdam, The Netherlands. http://claymore.rfmh.org/~ardekani/papers/ardekani04b.pdf. ISSN 0531-5131. ISBN 0444515674.

Arun, K. S., Huang, T. S., and Blostein, S. D. (1987). Least-squares fitting of two 3-D point sets. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 9(5):698–700. ISSN 0162-8828.

Ashburner, J. (2007). A fast diffeomorphic image registration algorithm. *NeuroImage*, 38(1):95–113. PMID: 17761438. http://users.fmrib.ox.ac.uk/~jesper/papers/readgroup_071009/Ashburner07.pdf.

Ashburner, J., Andersson, J. L. R., and Friston, K. J. (1999). High-dimensional image registration using symmetric priors. *NeuroImage*, 9(6):619–628. PMID: 10334905.

Ashburner, J., Andersson, J. L. R., and Friston, K. J. (2000). Image registration using a symmetric prior — in three dimensions. *Human Brain Mapping*, 9(4):212–225. PMID: 10770230.

Ashburner, J. and Friston, K. J. (1996). Fully three-dimensional nonlinear spatial normalization. In Belliveau, J., Fox, P., Kennedy, D., Rosen, B., and Ungeleider, L., editors, *Second International Conference on Functional Mapping of the Human Brain, NeuroImage*, volume 3, page S111. Academic Press. ISSN 1053–8119.

Ashburner, J. and Friston, K. J. (1997). Multimodal image coregistration and partitioning — a unified framework. *NeuroImage*, 6(3):209–217. PMID: 9344825.

Ashburner, J. and Friston, K. J. (1999). Nonlinear spatial normalization using basis functions. *Human Brain Mapping*, 7(4):254–266.

Ashburner, J., Neelin, P., Collins, D. L., Evans, A. C., and Friston, K. J. (1997). Incorporating prior knowledge into image registration. *NeuroImage*, 6(4):344–352. PMID: 9417976. http://www.idealibrary.com/links/citation/1053-8119/6/344. ISSN 1053-8119.

Bajcsy, R. and Kovacic, S. (1989). Multiresolution elastic matching. *Comput. Vis. Graph. Image Process.*, 46:1–21.

Bajcsy, R., Lieberson, R., and Reivich, M. (1983). A computerized system for the elastic matching of deformed radiographic images to idealised atlas images. *Journal of Cerebral Blood Flow and Metabolism*, 7(4):618–625. PMID: 6602820.

Bannister, P., Smith, S., Brady, M., and Jenkinson, M. (2002). Spatio-temporal realignment of FMRI data. *NeuroImage*, page 380. http://www.academicpress.com/journals/hbm2002/14125.html.

Bannister, P. R. and Jenkinson, M. (2001). Robust affine motion correction in fMRI time series. *NeuroImage*, 13(6):S70.

Biswal, B. B. and Hyde, J. S. (1997). Contour-based registration technique to differentiate between task-activated and head motion-induced signal variations in fMRI. *Magnetic Resonance in Medicine*, 38(3):470–476. PMID: 9339448.

Black, K. J., Koller, J. M., Snyder, A. Z., and Perlmutter, J. S. (2001a). Template images for nonhuman primate neuroimaging: 2. macaque. *NeuroImage*, 14(3):744–748. PMID: 11506546. DOI: 10.1006/nimg.2001.0871. ISSN 1053-8119.

Black, K. J., Snyder, A. Z., Koller, J. M., Gado, M. H., and Perlmutter, J. S. (2001b). Template images for nonhuman primate neuroimaging: 1. baboon. *NeuroImage*, 14(3):736–743. PMID: 11506545. DOI: 10.1006/nimg.2001.0752. ISSN 1053-8119.

Bookstein, F. (1989). Principal warps: Thin-plate splines and the decomposition of deformations. *IEEE Transactions of Pattern Analysis and Machine Intelligence*, 11(6):567–585.

Brammer, M. J. (2001). Head motion and its correction. In Jezzard, P., Matthews, P. M., and Smith, S. M., editors, *Functional MRI, an introduction to methods*, chapter 13, pages 243–250. Oxford University Press, Oxford, United Kingdom. ISBN 0192630717.

Brett, M. (2002). The MNI brain and the Talairach atlas. http://www.mrc-cbu.cam.ac.uk/Imaging-/Common/mnispace.shtml. Accessed 2005 April 9.

Brett, M. (2005). Modeling subject movement in fMRI. Eleventh Annual Meeting of the Organization for Human Brain Mapping. http://www.mrc-cbu.cam.ac.uk/~matthew/abstracts/Moves/moves.html.

Brett, M., Leff, A. P., Rorden, C., and Ashburner, J. (2001). Spatial normalization of brain images with focal lesions using cost function masking. *NeuroImage*, 14(2):486–500. PMID: 11467921. DOI: 10.1006/nimg.2001.0845. http://www.sciencedirect.com/science/article/B6WNP-457VFJT-1S/2/770d6c6f577ddcedbe31b4812083f5c3.

Bro-Nielsen, M. (1996). *Medical Image Registration and Surgery Simulation*. PhD thesis, Department of Mathematical Modelling, Technical University of Denmark, Lyngby, Denmark. IMM-PHD-1996-25. http://www.mortenbronielsen.net/phd_dissertation.htm.

Brown, L. G. (1992). A survey of image registration techniques. *ACM Computing Surveys*, 24(4):325–376. http://mirac.ee.ncku.edu.tw/~mol/research/seminar/phd2/20001027.pdf.

Bullmore, E. T., Brammer, M. J., Rabe-Hesketh, S., Curtis, V. A., Morris, R. G., Williams, S. C., Sharma, T., and McGuire, P. K. (1999). Methods for diagnosis and treatment of stimulus-correlated motion in generic brain activation studies using fMRI. *Human Brain Mapping*, 7(1):38–48. PMID: 9882089. http://www-bmu.psychiatry.cam.ac.uk/sitewide/publications/journal-/bullmore99met.pdf.

Chau, W. and McIntosh, A. R. (2005). The Talairach coordinate of a point in the MNI space: how to interpret it. *NeuroImage*, 25(2):408–416. PMID: 15784419.

Chef d'Hotel, C., Hermosillo, G., and Faugeras, O. (2002). Flows of diffeomorphisms for multimodal image registration. In *Proceedings of the IEEE International Symposium on Biomedical Imaging*, pages 21–28.

Christensen, G. E., Joshi, S., and Miller, M. I. (1997). Volumetric transformation of brain anatomy. *IEEE Transaction of Medical Imaging*, 16(6):864–877. PMID: 9533586.

Collignon, A., Maes, F., Delaere, D., Vandermeulen, D., Suethens, P., and Marchal, G. (1995). Automated multi-modality image registraction based on information theory. In Bizais, Y. and Di Paola, R., editors, *Information Processing in Medical Imaging*, pages 263–274, Amsterdam. Kluwer Academic.

Collins, D. L. (1994). *3D Model-based segmentation of individiual brain structures from magnetic resonance imaging data*. PhD thesis, Department of Biomedical Engineering, McGill University, Montreal, Canada. http://www.bic.mni.mcgill.ca/users/louis/papers/phd_thesis.

Collins, D. L., Holmes, C. J., Peters, T. M., and Evans, A. C. (1995). Automatic 3-D model-based neuroanatomical segmentation. *Human Brain Mapping*, 3(3):190–208.

Collins, D. L., Neelin, P., Peters, T. M., and Evans, A. C. (1994). Automatic 3D intersubject registration of MR volumetric data in standardized Talairach space. *Journal of Computer Assisted Tomography*, 18(2):192–205. PMID: 8126267.

Cox, R. W. (1996). Motion and functional MRI. Informal notes for the Boston'96 Workshop on Functional MRI. http://afni.nimh.nih.gov/afni/edu/regnotes.pdf.

Crivello, F., Schormann, T., Tzourio-Mazoyer, N., Roland, P. E., Zilles, K., and Mazoyer, B. M. (2002). Comparison of spatial normalization procedures and their impact on functional maps. *Human Brain Mapping*, 16(4):228–250. PMID: 12112765. http://www3.interscience.wiley.com/cgi-bin/abstract/94519609/.

Cusack, R., Brett, M., and Osswald, K. (2003). An evaluation of the use of magnetic field maps to undistort echo-planar images. *NeuroImage*, 18(1):127–142. PMID: 12507450.

Cusack, R. and Papadakis, N. (2002). New robust 3-D phase unwrapping algorithms: application to magnetic field mapping and undistorting echoplanar images. *NeuroImage*, 16(3):754–764. PMID: 12169259.

D'Agostino, E., Maes, F., Vandermeulen, D., and Suetens, P. (2004). Non-rigid atlas-to-image registration by minimization of class-conditional image entropy. In *Medical Image Computing and Computer-Assisted Intervention — MICCAI 2004*, volume 3216 of *Lecture Notes in Computer Science*, pages 745–753, Berlin. Springer.

Davatzikos, C. (1996). Spatial normalization of 3D brain images using deformable models. *Journal of Computer Assisted Tomography*, 20(4):656–665. PMID: 8708076. CiteSeer: http://citeseer.ist.psu.edu/15462.html.

Davatzikos, C. (1997). Spatial transformation and registration of brain images using elastically deformable models. *Computer Vision and Image Understanding*, 66(2):207–222. PMID: 11543561. CiteSeer: http://citeseer.ist.psu.edu/davatzikos97spatial.html. Special issue on Medical Imaging.

Davatzikos, C., Genc, A., Xu, D., and Resnick, S. M. (2001a). Voxel-based morphometry using the RAVENS maps: Methods and validation using simulated longitudinal atrophy. *NeuroImage*, 14(6):1361–1369. PMID: 11707092. DOI: 10.1006/nimg.2001.0937. http://www.rad.upenn.edu-/sbia/papers/RAVENS.pdf.

Davatzikos, C., Li, H. H., Herskovits, E., and Resnick, S. M. (2001b). Accurary and sensitivity of detection of activation foci in the brain via statistical parametric mapping: A study using a PET simulator. *NeuroImage*, 13(1):176–184. PMID: 11133320.

Desmond, J. E. and Atlas, S. W. (2000). Task-correlated head movement in fMR imaging: False activations can contaminate results despite motion correction. *American Journal of Neuroradiology*, 21(8):1370–1371. PMID: 11003264. http://www.ajnr.org/cgi/content/full/21/8/1370.

Diedrichsen, J. (2006). A spatially unbiased atlas template of the human cerebellum. *NeuroImage*, 33(1):127–128. http://www.bangor.ac.uk/~pss412/pubs/Neuroimage_2006.pdf.

Downs, J. H., Lancaster, J. L., and Fox, P. T. (1994). 3-D surface based spatial normalization using a convex hull. In Thatcher, R., Zeffino, T., and Huerta, M., editors, *Advances in functional neuroimaging: Technical foundations*, pages 131–136. Academic Press, Orlando, Florida.

Erwin, E., Baker, F., Busen, W., and Malpeli, J. (1999). Relationship between laminar topology and retinotopy in the rhesus lateral geniculate nucleus: results from a functional atlas. *Journal of Comparative Neurology*, 407:92–102.

Evans, A. C., Collins, D. L., Mills, S. R., Brown, E. D., Kelly, R. L., and Peters, T. M. (1993). 3D statistical neuroanatomical models from 305 MRI volumes. In Klaisner, L., editor, *Nuclear Science Symposium & Medical Imaging Conference: 1993 IEEE Conference Record*, pages 1813–1817. IEEE. http://ieeexplore.ieee.org/xpl/abs_free.jsp%3FarNumber%3D373602. ISBN 0780314883.

Evans, A. C., Collins, D. L., Neelin, P., MacDonald, D., Kamber, M., and Marrett, T. S. (1994). Three-dimensional correlative imaging: Applications in human brain mapping. In Thatcher, R. W., Hallett, M., Zeffiro, T., John, E. R., and Huerta, M., editors, *Functional Neuroimaging: Technical Foundations*, chapter 14, pages 145–161. Academic Press, San Diego, California. ISBN 0126858454. Describes their landmark based method for MRI-PET coregistration with validation using a PET simulation, as well as their matching algorithm based on a feature cross-correlation function for intra- and intersubject matching.

Evans, A. C., Dai, W., Collins, D. L., Neelin, P., and Marett, S. (1991). Warping of a computerized 3-D atlas to match brain image volumes for quantitative neuroanatomical and functional analysis. In Loew, M. H., editor, *Medical Imaging V: Image Processing*, volume 1445 of *Proceedings of SPIE*, pages 236–246, Bellingham, Washington. The International Society for Optical Engineering. http://bookstore.spie.org/index.cfm?fuseaction=DetailPaper&ProductId=45221. ISBN 081940540X.

Falangola, M. F., Ardekani, B. A., Lee, S.-P., Babb, J. S., Bogart, A., Dyakin, V. V., Nixon, R., Duff, K., and Helpern, J. A. (2005). Application of a non-linear image registration algorithm to quantitative analysis of T_2 relaxation time in transgenic mouse models of AD pathology. *Journal of Neuroscience Methods*, 144:91–97. http://cdr.rfmh.org/2005/pdfs-/Falangola_2005_JNeurosciMethods_Application.pdf.

Field, A. S., Yen, Y.-F., Burdette, J. H., and Elster, A. D. (2000). False cerebral activation on BOLD functional MR images: Study of low-amplitude motion weakly correlated to stimulus. *American Journal of Neuroradiology*, 21(8):1388–1396. PMID: 11003269. http://www.ajnr.org/cgi/content/abstract/21/8/1388. A phantom-study shows that submilliter movements influence the BOLD fMRI signal so much that statistical tests report false activation.

Finnis, K. W., Starreveld, Y. P., Parrent, A. G., and Peters, T. M. (2000). A 3-dimensional database of deep brain functional anatomy, and its application to image-guided neurosurgery. In Delp, S. L., Digioia, A. M., and Jaramaz, B., editors, *Medical Image Computing and Computer-Assisted Intervention — MICCAI 2000*, volume 1935 of *Lecture Notes in Computer Science*, pages 1–8, Berlin, Germany. Springer. http://www.irus.rri.on.ca/igns/documents/Miccai_2000.pdf. ISSN 0302-9743. ISBN 3540411895.

Fitzpatrick, J. M., West, J. B., and Clavin R. Maurer, J. (1998). Predicting error in rigid-body, point-based registration. *IEEE Transactions on Medical Imaging*, 17(5):694–702. PMID: 9874293. http://www.vuse.vanderbilt.edu/~image/registration/online_files/ieee_tmi_special.pdf.

Fize, D., Vanduffel, W., Nelissen, K., Denys, K., Chef d'Hotel, C., Faugeras, O., and Orban, G. A. (2003). The retinotopic organization of primate dorsal V4 and surrounding areas: a functinoal magnetic resonance imaging study in awake monkeys. *The Journal of Neuroscience*, 23(19):7395–7406. http://www.jneurosci.org/cgi/content/full/23/19/7395.

Fox, P. T. (1995). Spatial normalization origins: Objectives, applications, and alternatives. *Human Brain Mapping*, 3:161–164.

Fox, P. T., Pearlmutter, J. S., Reiman, E. M., and Raichle, M. E. (1985). A stereotactic method of anatomical localization for positron emission tomography. *Journal of Computer Assisted Tomography*, 9(1):141–153. PMID: 3881487.

Freire, L. and Mangin, J.-F. (2001a). Motion correction algorithms may create spurious brain activations in the absence of subject motion. *NeuroImage*, 14(3):709–722. PMID: 11506543. http://brainvisa.info/pdf/freire-NI01.pdf.

Freire, L. and Mangin, J.-F. (2001b). Motion correction algorithms of the brain mapping community create spurious functional activations. In Insana, M. F. and Leahy, R. M., editors, *Information Processing in Medical Imaging, 17th International Conference, IPMI 2001, Davis, CA, USA, June 18-22, 2001, Proceedings*, volume 2082 of *Lecture Notes in Computer Science*, pages 246–258, Heidelberg, Germany. Springer. http://link.springer.de/link/service/series/0558/bibs/2082/20820246.htm. ISBN 3540422455.

Freire, L., Roche, A., and Mangin, J.-F. (2002). What is the best similarity measure for motion correction in fmri time series? *IEEE Transaction of Medical Imaging*, 21(5):470–484. PMID: 12071618. http://brainvisa.info/pdf/freire-TMI02.pdf.

Friston, K. J., Ashburner, J., Frith, C. D., Poline, J.-B., Heather, J. D., and Frackowiak, R. S. J. (1995). Spatial registration and normalization of images. *Human Brain Mapping*, 3(3):165–189. DOI: 10.1002/hbm.460030303. http://www.fil.ion.ucl.ac.uk/spm/papers/SPM_1/.

Friston, K. J., Passingham, R. E., Hutt, J. G., Heather, J. D., Sawle, G. V., and Frackowiak, R. S. J. (1989). Localization of PET images: Direct fitting of the intercommissural (AC-PC) line. *Journal of Cerebral Blood Flow and Metabolism*, 9:690–699.

Friston, K. J., Williams, S., Howard, R., Frackowiak, R. S. J., and Turner, R. (1996). Movement-related effects in fMRI time-series. *Magnetic Resonance in Medicine*, 35(3):346–355. PMID: 8699946. http://www.fil.ion.ucl.ac.uk/spm/doc/papers/fMRI_1/fMRI_1.pdf.

Gee, J. C., Alsop, D. C., and Aguirre, G. K. (1997). Effect of spatial normalization on analysis of functional data. In Hanson, K. M., editor, *Medical Imaging 1997: Image Processing*, volume 3034 of *SPIE Proceedings*, pages 312–322, Bellingham. ISBN 0819424455.

Gee, J. C., Reivich, M., and Bajcsy, R. (1993). Elastically deforming 3D atlas to match anatomical brain images. *Journal of Computer Assisted Tomography*, 17(2):225–236. PMID: 8454749.

Gisbert, J. D., Pascau, J., Reig, S., Martínez-Lázaro, R., Molina, V., García-Barreno, P., and Desco, M. (2003). Influence of the normalization template on the outcome of statistical parametric mapping of PET scans. *NeuroImage*, 19(3):601–612. PMID: 12880791. DOI: 10.1016/S1053-8119(03)00072-7. An investigation of the influence of the template in functional neuroimaging, investigated with the choices using SPM99 for spatial normalization of PET FDG images: One choice with the default H20 template provided by SPM and two choices with a constructed FDG templates. One FDG template was constructed from the subjects by averaging spatial normalized FDG PET images that was normalized to the default SPM template, and another FDG template that was constructed by averaging FDG images whose deformation was estimated from MRI images. The last choice did not construct an FDG template and instead warped the subject PET-scans based on deformations estimated from the MRI images. A reported maximum z-score ranged from 4.13 to 4.60.

Gobbi, D. G. and Peters, T. M. (2003). Generalized 3D nonlinear transformations for medical imaging: an object-oriented implementation in VTK. *Computerized Medical Imaging and Graphics*, 27:255–265.

Greitz, T., Bohm, C., Holte, S., and Eriksson, L. (1991). A computerized brain atlas: construction, anatomical content, and some applications. *Journal of Computer Assisted Tomography*, 15(1):26–38. PMID: 1987199.

Grootoonk, S., Hutton, C., Ashburner, J., Howseman, A. M., Josephs, O., Rees, G., Friston, K. J., and Turner, R. (2000). Characterization and correction of interpolation effects in the realignment of fMRI time series. *NeuroImage*, 11(1):49–57. PMID: 10686116. DOI: 10.1006/nimg.1999.0515.

Hajnal, J. V., Myers, R., Oatridge, A., Schwieso, J. E., Young, I. R., and Bydder, G. M. (1994). Artefacts due to stimulus-correlated motion in functional images of the brain. *Magnetic Resonance in Medicine*, 31(3):283–291. PMID: 8057799.

Hellier, P., Ashburner, J., Corouge, I., Barillot, C., and Friston, K. J. (2002). Inter subject registration of functional and anatomical data using SPM. In T. Dohi, R. K., editor, *Medical Image Computing and Computer-Assisted Intervention - MICCAI 2002: 5th International Conference, Tokyo, Japan, September 25-28, 2002, Proceedings, Part II*, volume 2489, pages 590+, Berlin, Germany. Springer-Verlag. http://link.springer.de/link/service/series/0558/bibs/2489/24890590.htm.

Hellier, P., Barillot, C., Corouge, I., Gibaud, B., Goualher, G. L., Collins, D., Evans, A., Malandain, G., Ayache, N., Christensen, G., and Johnson, H. (2003). Retrospective evaluation of inter-subject brain registration. *IEEE Transaction on Medical Imaging*.

Hellier, P., Barillot, C., Corouge, I., Giraud, B., Goualher, G. L., Collins, L., Evans, A., Malandain, G., and Ayache, N. (2001). Retrospective evaluation of inter-subject brain registration. In Niessen, W. J. and Viergever, M. A., editors, *Medical Image Computing and Computer-Assisted Intervention - MICCAI 2001: 4th International Conference Utrecht, The Netherlands, October 14-17, 2001 Proceedings*, volume 2208 of *Lecture Notes in Computer Science*, pages 258–265, Berlin. Springer-Verlag. ftp://ftp-sop.inria.fr/epidaure/Publications/Hellier/22080258.pdf. CiteSeer: http://citeseer.ist.psu.edu/hellier01retrospective.html. ISBN 3540426973.

Hermosillo, G., Chef d'Hotel, C., and Faugeras, O. (2002). Variational methods for multimodal image matching. *International Journal of Computer Vision*, 50(3):329–343. DOI: 10.1023/A:1020830525823. ISSN 0920-5691.

Hermosillo, G., Chefd'Hotel, C., and Faugeras, O. (2001). A variational approach to multimodal image matching. Technical Report RR-4117, INRIA, Sophia Antipolis, France. ftp://ftp.inria.fr/INRIA/publication/publi-pdf/RR/RR-4117.pdf.

Hill, D. L. G., Hawkes, D. J., Studholme, C., Summers, P. E., and Taylor, M. G. (1994). Accurate registration and transformation of temporal image sequences. In *Proceedings of the 2nd Annual Meeting Society of Magnetic Resonance*, page 820. http://www-ipg.umds.ac.uk/d.hill/smr94.html.

Holmes, C. J., Hoge, R., Collins, D. L., Woods, R., Toga, A. W., and Evans, A. C. (1998). Enhancement of MR images using registration for signal averaging. *Journal of Computer Assisted Tomography*, 22(2):324–333. PMID: 9530404. http://www.jcat.org/pt/re/jcat/abstract.00004728-199803000-00032.htm.

Horsley, V. A. H. and Clarke, R. H. (1908). The structure and functions of the cerebellum examined by a new method. *Brain*, 31(1):45–124. http://www3.oup.co.uk/jnls/list/brainj/hdb/Volume_31/Issue_01/.

Hsu, C. C., Wu, M. T., and Lee, C. (2001). Robust image registration for functional magnetic resonance imaging of the brain. *Med. Biol. Eng. Comput.*, 39(5):517–524. PMID: 11712647.

Hutton, C., Bork, A., Josephs, O., Deichmann, R., Ashburner, J., and Turner, R. (2002). Image distortion correction in fMRI: A quantitative evaluation. *NeuroImage*, 16(1):217–240. PMID: 11969330. DOI: 10.1006/nimg.2001.1054. ISSN 1053-8119.

Ingvar, M., Bohm, C., Thurfjell, L., Eriksson, L., and Greitz, T. (1994). The role of a computerized adjustable brain atlas for merging of data from examinations using PET, SPECT, MEG, CT, and MR images. In Thatcher, R. W., Hallett, M., Zeffiro, T., John, E. R., and Huerta, M., editors, *Functional neuroimaging*, chapter 20, pages 209–215. Academic Press, San Diego, California.

Jenkinson, M. (2001). Improved unwarping of EPI images using regularised B0 maps. *NeuroImage*, 13(6):S165. http://www.cfn.unimelb.edu.au/markj/hbm2001.ps.

Jenkinson, M., Bannister, P., Brady, J. M., and Smith, S. M. (2002). Improved optimisation for the robust and accurate linear registration and motion correction of brain images. *NeuroImage*, 17(2):825–841. http://www.idealibrary.com/links/doi/10.1006/nimg.2002.1132.

Jenkinson, M. and Smith, S. (2000). Optimisation in robust linear registration of brain images. Technical Report TR00MJ2, Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB), Department of Clinical Neurology, University of Oxford, John Radcliffe Hospital, Oxford, United Kingdom. http://www.fmrib.ox.ac.uk/analysis/techrep/tr00mj2/tr00mj2/.

Jenkinson, M. and Smith, S. (2001). A global optimisation method for robust affine registration of brain images. *Medical Image Analysis*, 5(2):143–156. PMID: 11516708. http://www.sciencedirect.com/science/article/B6W6Y-438BMD5-5/1/44ad6f0c73041b66f8129cc39da670a7.

Jezzard, P. and Balaban, R. S. (1995). Correction for geometric distortion in echo planar images from b0 field variations. *Magnetic Resonance in Medicine*, 34(1):65–73. PMID: 7674900.

Johnstone, T., Ores Walsh, K. S., Greischar, L. L., Alexander, A. L., Fox, A. S., Davidson, R. J., and Oakes, T. R. (2005). Motion correction and the use of motion covariates in multiple-subject fMRI analysis. *Human Brain Mapping*. DOI: 10.1002/hbm.20219. In press.

Kiebel, S. J., Ashburner, J., Poline, J.-B., and Friston, K. J. (1997a). MRI and PET coregistration — a cross-validation of SPM and AIR. *NeuroImage*, 5(4):S531. A comparison of SPM(96) and AIR MRI and PET coregistration algorithms that shows that the two routines reliably solve the coregistration problem, that AIR perform better than SPM and that scalp-editing helps the coregistration.

Kiebel, S. J., Ashburner, J., Poline, J.-B., and Friston, K. J. (1997b). MRI and PET coregistration — a cross validation of statistical parametric mapping and automated image registration. *NeuroImage*, 5(4):271–279. PMID: 9345556.

Kjems, U. (1998). *Bayesian Signal Processing and Interpretation of Brain Images*. Ph.d. thesis, Department of Mathematical Modelling, Technical University of Denmark, IMM Building 321, DTU, 2800 Lyngby, Denmark. http://www.imm.dtu.dk/pubdb/views/publication_details.php?id=2473.

Kjems, U., Strother, S. C., Anderson, J. R., and Hansen, L. K. (1999a). Enhancing the multivariate signal of [15O] water PET studies with a new nonlinear neuroanatomical registration algorithm. *IEEE Transaction on Medical Imaging*, 18(4):306–319. PMID: 10385288. http://www.imm.dtu.dk/pubdb/views/publication_details.php?id=2837.

Kjems, U., Strother, S. C., Anderson, J. R., and Hansen, L. K. (1999b). A new unix toolbox for nonlinear warping of MR brain images applied to a [^{15}O] water PET functional experiment. In Rosen, B. R., Seitz, R. J., and Volkmann, J., editors, *Fifth International Conference on Functional Mapping of the Human Brain, NeuroImage*, volume 9, page S18. Academic Press. ISSN 1053–8119.

Kochunov, P., Lancaster, J. L., Thompson, P., Boyer, A., Hardies, J., and Fox, P. T. (2000). Evaluation of octree regional spatial normalization method for regional anatomical matching. *Human Brain Mapping*, 11:193–206.

Kochunov, P., Purdy, D., Lancaster, J., Laird, A., Gao, F., and Fox, P. (2006). High-resolution, retrospective motion correction anatomical MRI protocol for mapping gray matter thickness. In Corbetta, M., Nichols, T., and Pietrini, P., editors, *NeuroImage speciel issue: Twelfth Annual Meeting of the Organization for Human Brain Mapping*, volume 31, supplement 1. Elsevier. http://www.meetingassistant.com/ohbm2006/referee/abstract_popup.php?abstractno=260.

Kosugi, Y., Sase, M., Kuwatani, H., Kinoshita, N., Momose, T., Nishikawa, J., and Watabanabe, T. (1993). Neural network mapping for nonlinear stereotactic normalization of brain MR images. *Journal of Computer Assisted Tomography*, 17(3):455–460. PMID: 8491911.

Krishnan, S., Slavin, M. H., Tran, T. T., Doraiswamy, P. M., and Petrella, J. R. (2006). Accuracy of spatial normalization of the hippocampus: implications for fMRI research in memory disorders. *NeuroImage*, 31(2):560–571. PMID: 16513371.

Kybic, J., Thévenaz, P., Nirkko, A., and Unser, M. (2000). Unwarping of unidirectionally distorted EPI images. *IEEE Transactions on Medical Imaging*, 19(2):80–93. PMID: 10784280. http://bigwww.epfl.ch/publications/kybic0001.pdf. ISSN 0278-0062.

Lacey, A. J., Thacker, N. A., Burton, E., and Jackson, A. (1999). Locating motion artifacts in parametric fMRI analysis. In *Proceedings of the Second International Conference on Medical Image Computing and Computer-Assisted Intervention*, volume 1679 of *Lecture Notes In Computer Science*, pages 524–532, London, UK. Springer-Verlag. http://www.tina-vision.net/docs/memos/2001-002.pdf. ISBN :3-540-66503-X.

Lancaster, J. L., Fox, P. T., Downs, H., Nickerson, D. S., Hander, T. A., El Mallah, M., Kochunov, P. V., and Zamarripa, F. (1999). Global spatial normalization of the human brain using convex hulls. *Journal of Nuclear Medicin*, 40(6):942–955. PMID: 10452309.

Lancaster, J. L., Glass, T. G., Lankipalli, B. R., Downs, H., Mayberg, H., and Fox, P. T. (1995). A modality-independent approach to spatial normalization of tomographic images of the human brain. *Human Brain Mapping*, 3(3):209–223. DOI: 10.1002/hbm.460030305. http://www3.interscience.wiley.com/cgi-bin/fulltext/109711663/PDFSTART.

Lancaster, J. L., Kochunov, P., and Fox, P. T. (2001). An individual representative target brain in Talairach space. *NeuroImage*, 13(6, part 2):S180. http://www.apnet.com/www/journal/hbm2001/11325.html.

Lancaster, J. L., Tordesillas, D., Martinez, M., Mazziotta, J., Toga, A., Evans, A., Zilles, K., and Fox, P. T. (2006). Comparing Talairach and MNI reference frames using the ICBM-152 template. In Corbetta, M., Nichols, T., and Pietrini, P., editors, *NeuroImage speciel issue: Twelfth Annual Meeting of the Organization for Human Brain Mapping*, volume 31, supplement 1, Amsterdam. Elsevier. http://www.meetingassistant.com/ohbm2006/referee/abstract_popup.php?abstractno=441.

Lancaster, J. L., Tordesillas-Gutiérrez, D., Martinez, M., Salinas, F., Evans, A., K, K. Z., Mazziotta, J. C., and Fox, P. T. (2007). Bias between MNI and Talairach coordinates analyzed using the ICBM-152 brain template. *Human Brain Mapping*, 28(11):1194–1205. PMID: 17266101. DOI: 10.1002/hbm.20345. An investigation of how well affine spatial normalizations in SPM and FSL with ICBM-152 and MNI-305 templates fit with the Talairach atlas. Surprisingly their results show that Brett's mni2tal transformation usually does worse than nothing for the matching of MNI to Talairach, which to a certain extent is due to differencies in rotation about the x-axis. Three new affine transformations are suggested mapping from MNI space to Talairach space and these transformations are shown to be better than nothing or the Brett transformation. Their results shown that their new transformation are able to transform SPM2 and FSL normalized images so that landmarks are within a few millimeters of landmarks in Talairach space.

Lemieux, L., Salek-Haddadi, A., Lund, T. E., Laufs, H., and Carmichael, D. (2007). Modelling large motion events in fMRI studies of patients with epilepsy. *Magnetic Resonance Imaging*, 25(6):894–901. DOI: 10.1016/j.mri.2007.03.009. Proceedings of the International School on Magnetic Resonance and Brain Function.

Lohmann, G., Müller, K., Bosch, V., Mentzel, H., Hessler, S., Chen, L., Zysset, S., and von Cramon, D. Y. (2001). LIPSIA — a new software system for the evaluation of functional magnetic resonance images of the human brain. *Computerized Medical Imaging and Graphics*, 26(6):449–457. http://personal-homepages.mis.mpg.de/lchen/Ps/l.ps.gz.

Lund, T. E., Nørgaard, M. D., Rostrup, E., Rowe, J. B., and Paulson, O. B. (2005). Motion or activity: Their role in intra- and inter-subject variation in fMRI. *NeuroImage*, 26(3):960–964. DOI: 10.1016/j.neuroimage.2005.02.021. http://www.sciencedirect.com/science/article/B6WNP-4FTS2Y8-3/2/38fe9c149834758345d42dc8e35b70c9.

Maas, L. C., Frederick, B. D., and Renshaw, P. F. (1997). Decoupled automated rotational and translational registration for functional MRI time series data: The DART registration algorithm. *Magnetic Resonance in Medicine*, 37(1):131–139. PMID: 8978642.

Maes, F., Collignon, A., Vandermeulen, D., Marchal, G., and Suetens, P. (1997). Multimodality image registration by maximization of mutual information. *IEEE Transactions of Medical Imaging*, 16(2):187–198. PMID: 9101328.

Maes, F., Vandermeulen, D., and Suetens, P. (1999). Comparative evaluation of multiresolution optimization strategies for multimodality image registration by maximization of mutual information. *Medical Image Analysis*, 3(4):373–386. http://www.elsevier.com/gej-ng//10/31/36/51/28/28/abstract.html.

Maintz, J. B. A. and Viergever, M. A. (1998). A survey of medical image registration. *Medical Image Analysis*, 2(1):1–36. http://www.cs.uu.nl/people/twan/personal/media97.pdf. CiteSeer: http://citeseer.ist.psu.edu/maintz98survey.html.

Makris, N., Schmahmann, J. D., Kennedy, D. N., Benson, R. R., and Verne S. Caviness, J. (1996). Human cerebellar cortex: MRI-based topographic parcellation for localization and morphometry. *NeuroImage*, 3(1):S140.

Meijering, E. H. W., Niessen, W. J., and Viergever, M. A. (2001). Quantitative evaluation of convolution-based methods for medical image interpolation. *Medical Image Analysis*, 5(2):111–126. DOI: 10.1016/S1361-8415(00)00040-2.

Meyer, J. H., Gunn, R. N., Myers, R., and Grasby, P. M. (1999). Assessment of spatial normalization of PET ligand images using ligand specific templates. *NeuroImage*, 9(5):545–553. PMID: 10329294.

Miller, M. I., Christensen, G. E., Amit, Y., and Grenander, U. (1993). Mathematical textbook of deformable neuroanatomies. *Proceedings of the National Academy of Sciences of the United States of America*, 90(24):11944–11948. PMID: 8265653. http://www.pnas.org/cgi/reprint/90/24/11944.pdf.

Minoshima, S., Berge, K. L., Lee, K. S., and Mintun, M. A. (1992). An automated method for rotational correction and centering of three-dimensional functional brain images. *Journal of Nuclear Medicine*, 33(8):1572–1585. PMID: 1634959.

Minoshima, S., Koeppe, R. A., Frey, K. A., and Kuhl, D. E. (1994). Anatomic standardization: linear scaling and nonlinear warping of functional brain images. *Journal of Nuclear Medicine*, 35(9):1528–1537. PMID: 8071705.

Munger, P., Crelier, G. R., Peters, T. M., and Pike, G. B. (2000). An inverse problem approach to the correction of distortion in EPI images. *IEEE Transactions on Medical Imaging*, 19(7):681–689. PMID: 11055783.

Nagel, H. H. and Enkelmann, W. (1986). An investigation of smoothness constraints for the estimation of displacement vector-fields from image sequences. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 8(5):565–593.

Nielsen, M., Johansen, P., Jackson, A. D., and Lautrup, B. (2002). Brownian warps: A least committed prior for non-rigid registration. In Dohi, T. and Kikinis, R., editors, *Proceedings of Medical Image Computing and Computer-Assisted Intervention - MICCAI 2002*, volume 2488 of *Lecture Notes in Computer Science*, pages 557–564. Springer Verlag. http://www.nbi.dk/~lautrup/papers/miccai02.pdf.

Nowinski, W. L., Yang, G. L., and Yeo, T. T. (2000). Computer-aided stereotactic functional neurosurgery enhanced by the use of the multiple brain atlas database. *IEEE Transaction of Medical Imaging*, 19(1):62–69. PMID: 10782620.

Nowinski, W. L., Yeo, T. T., and Thirunavuukarasuu, A. (1998). Microelectrode-guided functional neurosurgery assisted by *electronic clinical brain atlas* CD-ROM. *Computer Aided Surgery*, 3(3):115–122. http://www3.interscience.wiley.com/cgi-bin/abstract/15001228/. ISSN 1092-9088.

Pellizzari, C. A., Chen, G. T. Y., Spelbrin, D. R., Ralph, R., Weichselbaum, R. R., and Chen, C. T. (1989). Accurate three dimensional registration of CT, PET and/or MRI images of the brain. *Journal of Computer-Assisted Tomography*, 13(1):20–26. PMID: 2492038.

Pfluger, T., Vollmar, C., Wismuller, A., Dresel, S., Berger, F., Suntheim, P., Leinsinger, G., and Hahn, K. (2000). Quantitative comparison of automatic and interactive methods for MRI-SPECT image registration of the brain based on 3-dimensional calculation of error. *Journal of Nuclear Medicine*, 41(11):1823–1829. PMID: 11079489. ISSN 0161-5505.

Pietrzyk, U., Herholz, K., Fink, G., A.Jacobs, Mielke, R., Slansky, I., Würker, M., and Heiss, W. D. (1994). An interactive technique for three-dimensional image registration: Validation for PET, SPECT, MRI and CT brain studies. *Journal of Nuclear Medicine*, 35(12):2011–2018. PMID: 7989986.

Poldrack, R. A. and Devlin, J. T. (2007). On the fundamental role of anatomy in functional imaging: Reply to commentaries on "in praise of tedious anatomy". *NeuroImage*, 37(4):1066–1068. DOI: 10.1016/j.neuroimage.2007.06.019. Discussion of issues around anatomical localization in functional neuroimaging and calls for better description of registration methods, stating that Brodmann areas are "often unnecessary and unwarranted" when reporting activation, and that standard space coordinates and an anatomical description should be reported.

Quinton, O., Gicquel, S., Tzourio, C., Mazoyer, N., Joliot, M., Mazoyer, B., and Alperovitch, A. (1999). EVA833: a statistical MRI brain atlas based on 833 elderly subjects. In *Fifth International Conference on Functional Mapping of the Human Brain*, page S101.

Rabiner, L. R., Schafer, R. W., and Rader, C. M. (1969). The chirp z-transform algorithm and its application. *Bell System Tech. J.*, 48:1249–1292.

Ramsøy, T. Z. (2007). *Age-effects on the functional architecture of the human medial temporal lobe*. PhD thesis, Danish Research Centre for Magnetic Resonance, Faculty of Health Sciences, Copenhagen University, Hvidovre, Denmark.

Roche, A., Malandain, G., Ayache, N., and Pennec, X. (1998a). Multimodal image registration by maximization of the correlation ratio. Technical Report RR-3378, INRIA, Sophia Antipolis, France. ftp://ftp.inria.fr/INRIA/publication/publi-pdf/RR/RR-3378.pdf.

Roche, A., Malandain, G., Pennec, X., and Ayache, N. (1998b). The correlation ratio as a new similarity measure for multimodal image registration. In *Proceedings of the First International Conference on Medical Image Computing and Computer-Assisted Intervention*, pages 1115–1124, London, UK. Springer-Verlag.

Roland, P. E., Fredriksson, J., Svensson, P., Amunts, K., Cavada, C., Hari, R., Cowey, A., Crivello, F., Geyer, S., Kostopoulos, G., Mazoyer, B., Poppelwell, D., Schleicher, A., Schormann, T., Seppa, M., Uylings, H., de Vos, K., and Zilles, K. (1999). ECHBD, a database for functional-structural and functional-functional relations in neuroimaging. In *Fifth International Conference on Functional Mapping of the Human Brain*, page S128.

Roland, P. E., Graufelds, C. J., Wåhlin, J., Ingelman, L., Andersson, M., Ledberg, A., Pedersen, J., Åkerman, S., Dabringhaus, A., and Zilles, K. (1994). Human brain atlas: For high-resolution functional and anatomical mapping. *Human Brain Mapping*, 1:173–184. ISSN 1065-9471.

Salmond, C. H., Ashburner, J., Vargha-Khadem, F., Connelly, A., Gadian, D. G., and Friston, K. J. (2002). The precision of anatomical normalization in the medial temporal lobe using spatial basis functions. *NeuroImage*, 17(1):507–512. PMID: 12482103. DOI: 10.1006/nimg.2002.1191. Examines the precision of spatial normalization with landmarks and finds about one millimeter standard deviation for optimal non-linear bases-based spatial normalization algorithm parameters and three millimeter for suboptimal.

Schmahmann, J. D., Doyon, J., McDonald, D., Holmes, C., Lavoie, K., Hurwitz, A. S., Kabani, N., Toga, A., Evans, A., and Petrides, M. (1996). Three-dimensional MRI atlas of the human cerebellum in proportional stereotaxic space. *NeuroImage*, 3(1):S122.

Schmahmann, J. D., Doyon, J., McDonald, D., Holmes, C., Lavoie, K., Hurwitz, A. S., Kabani, N., Toga, A., Evans, A., and Petrides, M. (1999). Three-dimensional MRI atlas of the human cerebellum in proportional stereotaxic space. *NeuroImage*, 10(3):233–260. DOI: 10.1006/nimg.1999.0459.

Schmahmann, J. D., Doyon, J., Toga, A. W., Petrides, M., and Evans, A. C. (2000). *MRI Atlas of the Human Cerebellum*. Academic Press, San Diego, California. ISBN 0126256659.

Schormann, T. and Dabringhaus, A. (2001). Statistics of nonlinear spatial distortions in histological images. In Moore, M., editor, *Spatial Statistics: Methodological Aspects and Applications*, volume 159 of *Lecture Notes in Statistics*, chapter 12, pages 247–262. Springer, New York.

Schormann, T., Henn, S., and Zilles, K. (1996). A new approach to gast elastic alignment with applications to human brains. In Höhne, K. H. and Kikinis, R., editors, *Visualization in Biomedical Computing, 4th International Conference, VBC '96, Hamburg, Germany, September 22–25, 1996, Proceedings*, volume 1131 of *Lecture Notes in Computer Science*, pages 337–342. Springer, Heidelberg, Germany. ISBN 3540616497.

Schormann, T., Posse, S., Henn, S., and Zilles, K. (1999). The new reference brain of the ECHB database. In *Fifth International Conference on Functional Mapping of the Human Brain, NeuroImage*, page S40.

Schormann, T. and Zilles, K. (1998). Three-dimensional linear and nonlinear transformation: an integration of light microscopical and MRI data. *Human Brain Mapping*, 6:339–347.

Schwarz, A. J., Danckaert, A., Reese, T., Gozzi, A., Paxinos, G., Watson, C., Merlo-Pich, E. V., and Bifone, A. (2006). A stereotaxic MRI template set for the rat brain with tissue class distribution maps and co-registered anatomical atlas: Application to pharmacological MRI. *NeuroImage*. PMID: 16784876.

Schweinhardt, P., Fransson, P., Olson, L., Spenger, C., and Andersson, J. L. R. (2003). A template for spatial normalisation of MR images of the rat brain. *Journal of Neuroscience Methods*, 129(2):105–113. DOI: 10.1016/S0165-0270(03)00192-4. http://www.sciencedirect.com/science/article/B6T04-49CRW4C-2/2/29ec41e9fd17bee0d079c9074c3b3dc1.

Seitz, R. J., Bohm, C., Greitz, T., Roland, P. E., Eriksson, L., Blomqvist, H., Rosenqvist, G., and Nordell, B. (1990). Accuracy and precision of the computerized brain atlas programme for localization and quantification in positron emission tomography. *Journal of Cerebral Blood Flow and Metabolism*, 10(4):443–457.

Shantha, T. R., Manocha, S. L., and Bourne, G. H. (1968). *A Stereotaxic Atlas of the Java Monkey Brain (Macaca irus)*. Williams & Wilkins, Baltimore.

Shen, D. and Davatzikos, C. (2002). HAMMER: hierarchical attribute matching mechanism for elastic registration. *IEEE Transactions in Medical Imaging*, 21(11):1421–1439. PMID: 12575879. http://www.rad.upenn.edu/~dgshen/papers/Hammer_TMI_V7.pdf.

Shen, D. and Davatzikos, C. (2003). Very high-resolution morphometry using mass-preserving deformations and HAMMER elastic registration. *NeuroImage*, 18(1):28–41. http://www.rad.upenn.edu/˜dgshen/papers/RavensHammer_V8.pdf.

Snyder, A. Z. (1996). Difference image vs. ratio image error function in PET-PET realignment. In Bailey, D. and Jones, T., editors, *Quantification of brain function using PET*, pages 131–137. Academic Press, San Diego, California.

St-Jean, P., Sadikot, A. F., Collins, D. L., Clonda, D., Kasrai, R., Evans, A. C., and Peters, T. M. (1998). Automated atlas integration and interactive three-dimensional visualization tools for planning and guidance in functional neurosurgery. *IEEE Transaction of Medical Imaging*, 17(5):672–680. PMID: 9874291.

Steinmetz, H., Furst, G., and Freund, H. J. (1990). Variation of perisylvian and calcarine anatomic landmarks within stereotaxic proportional coordinates. *American Journal of Neuroradiology*, 11(6):1123–1130. http://www.ajnr.org/cgi/content/abstract/11/6/1123.

Strother, S. C., Anderson, J. R., Xu, X. L., Liow, J. S., Bonar, D. C., and Rottenberg, D. A. (1994). Quantitative comparisons of image registration techniques based on high-resolution MRI of the brain. *Journal of Computer Assisted Tomography*, 18(6):954–962. PMID: 7962808.

Studholme, C., Constable, R. T., and Duncan, J. S. (1999). Incorporating an image distortion model in non-rigid alignment of EPI with conventional MRI. In Kuba, A., Samal, M., and Todd-Pokropek, A., editors, *Proceedings of Information Processing in Medical Imaging*, pages 454–459, Heidelberg. Springer Verlag. ISBN 3540661670.

Studholme, C., Constable, R. T., and Duncan, J. S. (2000). Accurate alignment of functional EPI data to anatomical MRI using a physics-based distortion model. *IEEE Transactions on Medical Imaging*, 19(11):1115–1127. PMID: 11204849.

Studholme, C., Hawkes, D. J., and Hill, D. L. (1998). Normalized entropy measure for multimodality image alignment. In Hanson, K. M., editor, *Medical Imaging 1998: Image Processing*, volume 3338 of *Proceedings of SPIE*, pages 132–143. SPIE. http://adsabs.harvard.edu/cgi-bin/nph-bib_query?1998SPIE.3338..132S.

Studholme, C., Hill, D. L. G., and Hawkes, D. J. (1997). Automated three-dimensional registration of magnetic resonance and positron emission tomography brain images by multiresolution optimization of voxel similarity measures. *Medical Physics*, 24(1):25–35. PMID: 9029539.

Sugiura, M., Kawashima, R., Sadato, N., Senda, M., Kanno, I., Oda, K., Sato, K., Yonekura, Y., and Fukuda, H. (1999). Anatomic validation of spatial normalization methods for PET. *Journal of Nuclear Medicine*, 40:317–322.

Sugiura, M., Kawashima, R., Senda, M., Kanno, I., Sadato, N., Oda, M., Inoue, K., Kinomura, S., Sato, K., and Fukuda, H. (1997). Anatomical validation of spatial registration and normalization methods on PET. *NeuroImage*, 5(4):S398.

Szabo, J. and Cowan, W. M. (1984). A stereotaxic atlas of the brain of the cynomolgus monkey (macaca fascicularis). *Journal of Comparative Neurology*, 222(2):265–300. PMID: 6365984.

Talairach, J. and Tournoux, P. (1988). *Co-planar Stereotaxic Atlas of the Human Brain*. Thieme Medical Publisher Inc, New York. ISBN 0865772932.

Thacker, N. A., Burton, E., Lacey, A. J., and Jackson, A. (1999). The effects of motion on parametric fMRI analysis techniques. *Physiological Measurement*, 20(3):251–263. http://www.niac.man.ac.uk-/˜nat/fmrimotion.ps.

Thesen, S., Heid, O., Mueller, E., and Schad, L. R. (2000). Prospective acquisition correction for head motion with image-based tracking for real-time fMRI. *Magnetic Resonance in Imaging*, 44(3):457–465. PMID: 10975899.

Thévenaz, P., Blu, T., and Unser, M. (2000). Interpolation revisited. *IEEE Transactions in Medical Imaging*, 19(7):739–758. http://bigwww.epfl.ch/publications/thevenaz0002.pdf.

Thévenaz, P., Ruttimann, U. E., and Unser, M. (1995). Iterative multi-scale registration without landmarks. In *Proc. IEEE Int. Conf. on Image Processing, Washington, DC, USA, October 23-26, 1995*, volume 3, pages 228–231. http://bigwww.epfl.ch/publications/thevenaz9501.pdf.

Thévenaz, P. and Unser, M. (1998). A pyramid approach to subpixel registration based on intensity. *IEEE Transactions on Image Processing*, 7(1):27–41. http://bigwww.epfl.ch/publications/thevenaz9801.pdf.

Thévenaz, P. and Unser, M. (2000). Optimization of mutual information for multiresolution image registration. *IEEE Transactions on Image Processing*, 9(12):2083–2099. http://bigwww.epfl.ch/publications/thevenaz0003.pdf.

Thirion, J.-P. (1998). Image matching as a diffusion process: an analogy with Maxwell's demons. *Medical Image Analysis*, 2(3):243–260.

Thompson, P. M., MacDonald, D., Mega, M. S., Holmes, C. J., Evans, A. C., and Toga, A. W. (1997). Detection and mapping of abnormal brain structure with a probabilistic atlas of cortical surfaces. *Journal of Computer Assisted Tomography*, 21(4):567–581. http://www.loni.ucla.edu/˜thompson/JCAT.html.

Thurfjell, L., Bohm, C., and Bengtsson, E. (1995). CBA — an atlas-based software tool used to facilitate the interpretation of neuroimaging data. *Computer Methods and Programs in Biomedicine*, 47(1):51–71. PMID: 7554863. DOI: 10.1016/0169-2607(95)01629-8. http://www.sciencedirect.com/science/-article/B6T5J-3YXBJHX-S/2/78597e854cedf40f431306530264a04.

Toga, A. W., editor (1998). *Brain Warping*. Academic Press. ISBN 0126925356.

Toga, A. W. and Thompson, P. (2000). Multimodal brain atlases. Accessed 2005 November 15. http://www.loni.ucla.edu/˜thompson/whole_atlas.html.

Unser, M., Aldroubi, A., and Gerfen, C. (1993). A multiresolution image registration procedure using spline pyramids. In Laine, A. F., editor, *Wavelet Applications in Signal and Image Processing*, volume 2034 of *SPIE Proceedings*, pages 160–170, Bellingham, Washington. The International Society for Optical Engineering.

Viergever, M. A., Maintz, J. B., and Stokking, R. (1997). Integration of functional and anatomical brain images. *Biophys. Chem.*, 68(1–3):207–219. PMID: 9468620.

Viola, P. and Wells III, W. M. (1995). Alignment by maximization of mutual information. In *Proceedings of the Fifth International Conference on Computer Vision*, pages 16–23. CiteSeer: http://citeseer.ist.psu.edu/68246.html.

Watabe, H., Koshino, K., Bloomfield, P. M., Fulton, R. F., and Iida, H. (2004). Development of motion correction technique for PET study using optical tracking system. In Iida, H., Shah, N. J., Hayashi, T., and Watabe, H., editors, *Quantification in Biomedical Imaging with PET and MRI: Proceedings of the International Workshop on Quantification in Biomedical Imaging with PET and MRI held in Osaka, Japan, between 26 and 27 January 2004*, volume 1265 of *International Congress Series*, pages 31–38. Elsevier, Amsterdam, The Netherlands. ISSN 0531-5131. ISBN 0444515674.

Wells III, W. M., Viola, P., Atsumi, H., Nakajima, S., and Kikinis, R. (1996). Multi-modal volume registration by maximisation of mutual information. *Medical Image Analysis*, 1(1):35–51. PMID: 9873920. CiteSeer: http://citeseer.ist.psu.edu/wells95multimodal.html.

West, J., Fitzpatrick, J. M., Wang, M. Y., Dawant, B. M., Maurer Jr, C. R., Kessler, R. M., Maciunas, R. J., Barillot, C., Lemoine, D., Collignon, A., Maes, F., Suetens, P., Vandermeulen, D., van den Elsen, P. A., Napel, S., Sumanaweera, T. S., Harkness, B., Hemler, P. F., Hill, D. L., Hawkes, D. J., Studholme, C., Maintz, J. B., Viergever, M. A., Malandain, G., and

Woods, R. P. (1997). Comparison and evaluation of retrospective intermodality brain image registration techniques. *Journal of Computer Assisted Tomography*, 21(4):554–566. PMID: 9216759. http://www.vuse.vanderbilt.edu/~image/registration/online_files/jcat_97.pdf.

Willendrup, P., Pinborg, L. H., Hasselbalch, S. G., Adams, K. H., Stahr, K., and Knudsen, G. M. (2004). Assessment of the precision in co-registration of structural MR images and PET images with localized binding. In Iida, H., Shah, N. J., Hayashi, T., and Watabe, H., editors, *Quantification in Biomedical Imaging with PET and MRI: Proceedings of the International Workshop on Quantification in Biomedical Imaging with PET and MRI held in Osaka, Japan, between 26 and 27 January 2004*, volume 1265 of *International Congress Series*, pages 275–280. Elsevier, Amsterdam, The Netherlands. ISSN 0531-5131. ISBN 0444515674. Comparison of IIO, IPS, AIR and SPM99 coregistration methods between MRI and FDG-PET and altanserin-PET. It is found that the automated methods (SPM and AIR) performs better than the manual (IIO and IPS) on FDG-PET scans while the manual performs better on the altanserin-PET where cerebellum signal is missing.

Willendrup, P., Svarer, C., Hasselbach, S. G., and Knudsen, G. M. (2002a). Comparison of coregistration techniques for neuroreceptor PET images. In *The 49th Society of Nuclear Medicine Annual Meeting*, page S853, Reston, VA, USA. Society for Nuclear Medicine.

Willendrup, P., Svarer, C., Hasselback, S. G., and Knudsen, G. M. (2002b). Precision of coregistration techniques for F18-altanserin PET images. In Cunningham, V. J. and Myers, R., editors, *NeuroImage*, volume 16, page S85. Elsevier Science. The Fourth International Symposium on Functional Neuroreceptor Mapping of Living Brain.

Woods, R. P., Cherry, S. R., and Mazziotta, J. C. (1992). Rapid automated algorithm for alignment and reslicing PET images. *Journal of Computer Assisted Tomography*, 16(4):634–639. PMID: 1629424.

Woods, R. P., Dapretto, M., Sicotte, N. L., Toga, A. W., and Mazziotta, J. C. (1999). Creation and use of a Talairach-compatible atlas for accurate, automated, nonlinear intersubject registration, and analysis of functional imaging data. *Human Brain Mapping*, 8(2–3):73–79. PMID: 10524595. http://www3.interscience.wiley.com/cgi-bin/abstract/66000625/. ISSN 1097-0193. Special Issue: Proceedings of the Brainmap '98 Workshop. Describes construction of T1 and T2 MRI brain atlases in Talairach space based on ten subjects. The T1 template was constructed with an initial affine intersubject transformation, a nonlinear 495-parameter intersubject warping, a rigid body atlas transformation to Talairach space, and finally a scaling to fit the extent of the Talairach atlas. The T2 EPI template was constructed by intermodality registration with the T1 images. Also describes motion alignment.

Woods, R. P., Grafton, S. T., Holmes, C. J., Cherry, S. R., and Mazziotta, J. C. (1998a). Automated image registration. I general methods and intrasubject, intramodality validation. *Journal of Computer Assisted Tomography*, 22(1):139–152. PMID: 9448779.

Woods, R. P., Grafton, S. T., Watson, J. D. G., Sicotte, N. L., and Mazziotta, J. C. (1998b). Automated image registration. II. intersubject validation of linear and nonlinear models. *Journal of Computer Assisted Tomography*, 22(1):153–165. PMID: 9448780.

Woods, R. P., Mazziotta, J. C., and Cherry, S. R. (1993). MRI-PET registration with automated algorithm. *Journal of Computer Assisted Tomography*, 17(4):536–546.

Index