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Comparison of the disparity between Talairach and MNI coordinates in functional neuroimaging data: Validation of the Lancaster transform

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Abstract

Spatial normalization of neuroimaging data is a standard step when assessing group effects. As a result of divergent analysis procedures due to different normalization algorithms or templates, not all published coordinates refer to the same neuroanatomical region. Specifically, the literature is populated with results in the form of MNI or Talairach coordinates, and their disparity can impede the comparison of results across different studies. This becomes particularly problematic in coordinate-based meta-analyses, wherein coordinate disparity should be corrected to reduce error and facilitate literature reviews. In this study, a quantitative comparison was performed on two corrections, the Brett transform (i.e., “mni2tal”), and the Lancaster transform (i.e., “icbm2tal”). Functional magnetic resonance imaging (fMRI) data acquired during a standard paired associates task indicated that the disparity between MNI and Talairach coordinates was better reduced via the Lancaster transform, as compared to the Brett transform. In addition, an activation likelihood estimation (ALE) meta-analysis of the paired associates literature revealed that a higher degree of concordance was obtained when using the Lancaster transform in the form of fewer, smaller, and more intense clusters. Based on these results, we recommend that the Lancaster transform be adopted as the community standard for reducing disparity between results reported as MNI or Talairach coordinates, and suggest that future spatial normalization strategies be designed to minimize this variability in the literature.

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Keywords

Talairach; MNI; coordinate disparity; spatial normalization; icbm2tal; mni2tal; Lancaster transform; Brett transform

Introduction

In the analysis of neuroimaging data, it is common practice to spatially normalize subject brains to a standard coordinate system in order to reduce intersubject variability, enable intersubject image averaging, and facilitate the reporting of reduced results in the form of stereotactic (*x*,*y*,*z*) coordinates. Numerous registration methods exist, including manual vs. automated and linear vs. nonlinear approaches. In addition, there are a number of different brain spaces or templates that are used as spatial normalization targets. The two most prevalent are based on the Talairach atlas (Talairach and Tournoux, 1988) and the Montreal Neurological Institute (MNI) templates (Evans et al., 1993; Collins et al., 1994). Two of the most common software packages, SPM and FSL, distribute MNI templates for use as targets during automated spatial normalization. However, despite their large users bases, a significant percentage of functional neuroimaging results in the literature have been reported in Talairach space (Table 1).

Talairach space is defined as the standard brain space with the same dimensions as the published 1988 atlas (x = 136 mm, y = 172 mm, z = 118 mm), in which the principal axis corresponds to the anterior commissure-posterior commissure (AC-PC) line, and the origin lies at the AC. In contrast, the MNI templates do not conform to this system, and are characterized by differences in origin, orientation, and larger dimensions (Lancaster et al., 2007). It is widely known that Talairach coordinates do not refer to the same brain structures as MNI coordinates, and vice versa (Lancaster et al., 2007; Lacadie et al., 2008; Chau and McIntosh, 2005; Brett et al., 2002).

The disparity between Talairach and MNI coordinates can impede the comparison of results across different studies, either when comparing small groups of individual publications or results archived in a large-scale database, such as the BrainMap database (Fox and Lancaster, 2002; Laird et al., 2005a). MNI-Tal disparity is particularly problematic in the case of coordinate-based, voxel-wise meta-analysis (CVM) (Fox et al., 2005). In CVM, coordinates published in studies examining similar tasks or cognitive or perceptual processes are pooled from the existing literature to search for spatial agreement. Generally, these studies include a mixture of both Talairach and MNI coordinates. As a pre-processing step, input coordinates must be spatially re-normalized so they all refer to the same standard space. Thus, a valid conversion between Talairach and MNI coordinates is required to accurately assess the localization of agreement across published studies. Until recently, the only well-known transformation between MNI and Talairach coordinates was the Brett transform (sometimes referred to as “mni2tal”; Brett et al., 2002). However, a study by Lancaster et al. (2007) provided an alternative method, which was shown to provide improved fit over the Brett transform, and has since been designated the “icbm2tal” conversion.

In the present investigation, a comparison of the effects of the Brett and Lancaster transforms was carried out in functional magnetic resonance imaging (fMRI) data during a face-name paired associates task. The paired associates task is a standard paradigm that is commonly used to measure brain activity during memory encoding and retrieval processes, and has been employed in a number of published fMRI and PET studies. Using this previous literature, we performed a second comparison of the Brett and Lancaster transforms in

coordinate-based activation likelihood estimation (ALE) meta-analysis (Turkeltaub et al., 2002) of paired associates imaging data. Here, we demonstrate that the Lancaster transform provides a better fit to reducing coordinate disparity than the Brett transform in functional neuroimaging studies across results in both individual studies and coordinate-based meta-analyses.

Methods

fMRI Paradigm

Thirty-nine participants (age: 31.76±10.28 years, 19 males) performed a face-name paired associates task modeled after Zeineh et al., 2003. The task included three phases: Learn, Recall, and Baseline. During the Learn phase, participants were presented with eight face-name pairs (4 men, 4 women) and asked to remember each person's name. During the Recall phase, subjects were presented with a single face along with four names and asked to recall which name was associated with that face. The same face-name pairs were presented twice. During the active Baseline phase, subjects were simply asked to press either the right or left button corresponding to an arrow presented on the screen. There were eight Learn blocks and eight Recall blocks, each 24 seconds long, that were separated by a 15 second Baseline block. The entire task took approximately nine minutes to complete.

fMRI Image Acquisition and Analysis

Scanning was carried out on a Siemens 3T MRI housed in the Research Imaging Center at UTHSCSA. Functional images were acquired using a gradient echoplanar sequence, acquiring 26 slices (3mm thick, 1mm gap) parallel to the AC-PC plane (TR/TE = 3000/30ms, 128×128×5mm, and FOV = 256mm). For anatomical reference, a higher resolution co-planar T1-weighted series (TR/TE = 500/20ms, flip angle = 90 degrees, 128×128×5mm, FOV = 256cm) and a high-quality 3D image (TR/TE = 33/12ms, and flip angle = 60 degrees, 1mm isotropic) were also acquired.

Image analysis was carried out using FEAT (FMRI Expert Analysis Tool) Version 5.63, part of FSL Version 3.3 (FMRIB's Software Library; www.fmrib.ox.ac.uk/fsl). Pre-statistics processing was applied including motion correction using MCFLIRT (Jenkinson et al., 2002), non-brain removal using BET (Brain Extraction Tool; Smith et al., 2002), spatial smoothing using a Gaussian kernel of 5mm FWHM, mean-based intensity normalization of all volumes by the same factor, and high-pass temporal filtering (Gaussian-weighted least-squares straight line fitting, with sigma=50.0s). Time-series statistical analysis was carried out using FILM (FMRIB's Improved Linear Model) with local autocorrelation correction (Woolrich et al., 2001).

Least-squares coefficients were generated for each intracranial voxel independently for Learn, Recall, and Baseline conditions, and contrasts between these coefficients were used to create the statistical images. Higher-level analyses were performed with a mixed-effects model where subject was treated as a random effect and images contrasting the Learn and Recall conditions versus the control task (Baseline), respectively, were generated. Images were also generated for the contrasts of Learn > Recall and Recall > Learn. Group maps were thresholded based on the magnitude ($z \geq 4.00$) and extent (cluster $P < 0.05$) of activation.

Comparison of fMRI Coordinates

Two sets of statistical images were created for each contrast using different techniques for spatially normalizing images to standard stereotactic space to facilitate multi-subject analysis. The first set of images was normalized to the MNI template included in FSL 3.3

(ICBM-152 T1 average) using FLIRT (FMRIB's Linear Image Registration Tool). The second set of images was manually normalized to Talairach space using a standard set of 8 anatomical landmarks (anterior and posterior commissures and the anterior, posterior boundary, left, right, superior, and inferior boundaries of the brain) in conjunction with the global scaling affine transformation method as implemented in the Spatial Normalization (SN) software package (Lancaster et al., 1995).

MNI or Talairach coordinates were extracted from the statistical images for the four contrasts of interest (Learn > Baseline, Recall > Baseline, Learn > Recall, Recall > Learn). MNI coordinates were converted to Talairach space twice using (1) the Lancaster transform (i.e., “icbm2tal”) or, (2) the Brett transform (i.e., “mni2tal”). Coordinate conversions were carried out using GingerALE 1.1, which is distributed by the BrainMap project (http://brainmap.org). Euclidean distances from the Talairach coordinates to the converted Talairach coordinates were computed and averaged for each contrast.

ALE Literature Meta-Analysis

In an activation likelihood estimation (ALE) meta-analysis, three-dimensional coordinates in stereotactic space are collected and filtered from a number of similar studies, and pooled to search for convergence in space (Turkeltaub et al, 2002; Laird et al., 2009). Each reported coordinate (focus) is modeled by a three-dimensional Gaussian distribution, defined by a user-specified FWHM (full width at half maximum). The ALE statistic is computed at each voxel in the brain, and quantifies the likelihood of activation at a given voxel, for a given task, as determined by the chosen set of studies from the literature.

A PubMed search was carried out to identify published studies that utilized the paired associates task and investigated brain activations during the encoding or recall/recognition of paired stimuli in normal subjects. Paired stimuli mainly included pairs of words, but also included picture pairs, word-picture pairs, face-name pairs, and word-sound pairs (Appendix). Deactivations (e.g., baseline > encoding), as well as high-level contrasts (e.g., visual – auditory, incorrect vs. correct), were excluded from the meta-analysis. Coordinate results were divided into two groups based on the task instructions: encoding (16 papers with 22 contrasts) or recall (17 papers with 28 contrasts). ALE meta-analyses were performed separately on the coordinates for encoding (245 foci) and recall (213 foci) using a FWHM of 10mm (Turkeltaub et al., 2002). The meta-analysis was performed three times in Talairach space, in which all MNI coordinates were spatially renormalized using (1) the Brett transform, (2) the Lancaster transform, or (3) no transform. Statistical significance was determined using a permutation test of 5000 permutations (Laird et al., 2005b). The ALE images were thresholded at $P < 0.05$, FDR-corrected. Euclidean distances between ALE clusters that were observed across the Brett-converted, Lancaster-converted, and unconverted coordinates were computed and averaged to determine the magnitude of effect due to the transform method.

Results

fMRI Results: Brett vs. Lancaster

For each contrast (Learn > Baseline, Recall > Baseline, Learn > Recall, Recall > Learn), Talairach and MNI coordinates were closely examined via visual inspection to determine the corresponding pairs (i.e., first isolating clusters with similar *z* coordinates, then comparing *x* and *y* coordinates). Small differences in cluster centers of mass and extents were observed between the sets of images; however, the results between templates were generally well paired. For example, in the Recall > Baseline contrast, 7 matching pairs of Talairach and MNI coordinates were identified. MNI coordinates were converted to Talairach coordinates

using the Brett or Lancaster transform for this contrast, and the average distance was computed for each paired cluster (Table 2). The coordinate conversions and distance calculations were repeated for the three other contrasts (Table 3). MNI coordinates converted using the Lancaster transform more closely matched the Talairach coordinates (average distance between Talairach and converted Talairach coordinates = **6.284 mm**), as compared to those coordinates that were not transformed from MNI space (average distance = **7.782 mm**). Coordinates that were transformed using the Brett transform yielded the poorest match to Talairach coordinates (average distance = **8.451 mm**), effectively increasing the disparity between MNI and Talairach coordinates.

ALE Meta-Analysis Results: Brett vs. Lancaster

For the both the encoding and recall foci, three separate coordinate-based meta-analyses were performed in which published MNI coordinates were (1) converted using the Brett transform, (2) converted using the Lancaster transform, or (3) not subjected to any conversion algorithm. ALE images ($P<0.05$, FDR-corrected) of both encoding and recall were highlighted by regions of convergence in the medial and left lateral prefrontal cortices, as well as medial temporal and posterior parietal cortices.

A total of 23 studies were meta-analyzed, including 10 papers that published Talairach coordinates, 11 with MNI coordinates, and 2 papers that utilized the Brett transform to convert MNI coordinates to Talairach space (Appendix). Figure 1 displays the different results obtained in the encoding meta-analysis when using the Lancaster (red) or Brett (green) transforms. Use of the different transform algorithms leads to an observable shift in the ALE results, notably in that the Brett transform performs a nose-down correction of MNI coordinates, while the Lancaster transform performs a nose-up correction. In agreement with the results of Lancaster et al. (2007), the results were most closely matched within medial temporal areas, and the differences were the greatest in anterior and superior regions.

When comparing meta-analyses performed using the Lancaster or Brett transforms, different patterns of convergence were observed – some ALE clusters changed in position and/or size, while others experienced a splitting or joining effect (Table 4). Overall, fewer clusters were found in the Lancaster meta-analysis, with an average distance of 7.5mm between Lancaster and Brett coordinates. This is due to a higher degree of concordance in the altered distribution of coordinates when differences in spatial normalization template are accurately controlled. For example, in the Brett meta-analysis, two proximate yet separate clusters were observed in BA 47 of the inferior frontal gyrus (-40, 24, -14 and -36, 24, -4). In the Lancaster meta-analysis, proper alignment of input coordinates yielded a single cluster in this region (-38, 24, -8) of greater ALE intensity (ALE = 0.0117 as compared to ALE = 0.0115 and 0.0107).

Several observed clusters in the Brett meta-analyses were found to converge into tighter nodes in the Lancaster meta-analysis. For encoding and recall, a total of seven ALE clusters from the Lancaster meta-analysis were split into multiple clusters in the Brett meta-analysis, while only one Brett cluster was split into two clusters in the Lancaster meta-analysis. ALE scores from clusters in the Lancaster meta-analyses were frequently greater than the ALE scores from corresponding clusters in the Brett meta-analyses. The average maximum ALE score for the meta-analyses was slightly greater for the Lancaster meta-analyses (0.0105) as compared to the Brett meta-analyses (0.0103); however, this difference was not statistically significant. A subtraction meta-analysis (Laird et al., 2005b) was performed to determine if there were any regions of significant statistical difference for the Lancaster and Brett meta-analyses; this analysis confirmed several areas of significant difference between the two meta-analysis that were located in superior and anterior regions of the cortex. In sum, we observed fewer, smaller, and in some cases, more intense clusters in the Lancaster meta-

analyses when compared to the Brett meta-analyses, which may indicate a truer match between functional regions that is found across studies when MNI coordinates are converted using the Lancaster transform.

Discussion

A quantitative comparison was performed on the relative ability of the Brett transform (i.e., “mni2tal”) (Brett et al., 2002) and the Lancaster transform (i.e., “icbm2tal”) (Lancaster et al., 2007) to correct for the disparity that exists between Talairach and MNI coordinates. The fMRI data of paired associates encoding and recall demonstrate that a reduction in disparity between Talairach and MNI coordinates is possible using the Lancaster transform, and that the Brett transform actually results in a poorer fit than if no conversion algorithm is applied to the MNI coordinates. As a second comparison of the Brett and Lancaster transforms, coordinate-based meta-analyses of the published paired associates literature were performed using activation likelihood estimation (ALE) (Turkeltaub et al., 2002) to determine if the choice of transform has a substantial effect on the observed concordance patterns. Analysis revealed that the Lancaster transform results in tighter, more coherent nodes of concordance. Taken together, these results indicate that the choice of transform (e.g., Lancaster or Brett) does have an impact on the reporting of functional neuroimaging results and should therefore not be overlooked during quantitative comparison across studies. Our results were not intended to address accurate alignment with the anatomical labels delineated by the 1988 Talairach atlas, but rather to test different methods for comparing and meta-analyzing coordinates that have already been normalized to Talairach space using accepted anatomical landmarks and transformation techniques. While linear transformations are not able to match brain shape in the same way possible with nonlinear transformations, there exist a large number of coordinates in the literature derived from affine transformations to Talairach space (Table 1). It is important that the best methods be made available to ensure that these published Talairach coordinates are comparable to published MNI coordinates, and the results of the present study suggest that the Lancaster transform provides improved outcome over the Brett transform.

Community software packages currently provide both linear and piecewise linear Talairach transformation methods, the latter of which involves dividing Talairach space into a proportional grid of 12 sub-volumes (based on axes defined from anatomical landmarks) and scaling each region independently. In 1994, our group adopted the global scaling approach since the piecewise linear technique was originally intended as a strategy for improving localization within a specific sub-volume in neurosurgical applications. In contrast, the global scaling method provides a whole-brain fit with minimal distortion (Lancaster et al., 1995). This method was used to develop the Lancaster transform, and the present comparison of coordinate disparity does not include an analysis of how our results may differ for piecewise linear mappings. To our knowledge, no study exists that quantifies the effects of linear vs. piecewise linear normalization to Talairach space. However, Chau and McIntosh (2005) compared coordinates extracted from images normalized to the ICBM-152 template in SPM99 to coordinates derived from piecewise linear normalization to Talairach space. They observed that the disparity between coordinates converted using the Brett transform ranged from 3.0-9.5 mm (we note that the average distance of 8.451 mm obtained here for Brett transform disparity is within this range). In addition, Chau and McIntosh reported similar effects of the Brett transform, notably that it produces the largest discrepancies in inferior, superior frontal, and occipital regions. Using data from Table 2 of Chau and McIntosh, we calculated that the corresponding average discrepancy for their set of coordinates corrected using the Lancaster transform is 5.76 mm, which is smaller than what was computed for the Brett transform (6.27 mm). Thus, although the Lancaster transform was developed using the global scaling method, there is evidence to suggest that it

provides improved fit over the Brett transform even for cases in which images were normalized to Talairach space using the piecewise linear scaling method.

The present study highlights a need for better publishing standards when reporting the reference space to which coordinates refer. This is an issue that has been previously raised (Poldrack et al., 2008; Van Essen and Dierker, 2007); however, this is a critical point that needs to be reiterated as it has important implications for both coordinate-based meta-analyses and neuroinformatics initiatives such as the BrainMap database (Fox and Lancaster, 2002; Laird et al, 2005a). Frequently, authors can be misleading or vague when citing the brain template used during spatial normalization. Authors should be encouraged to make a clearer distinction between the basic coordinate system as defined by Talairach and Tournoux (1998) and the reference template corresponding to a standard brain that was used during spatial normalization. Confusion between these two components of the analysis has led to frequent ambiguity in the literature. A working group has been established to provide specific guidelines on this and other issues, which should aid authors in identifying and following the appropriate standards when preparing manuscripts (http://www.fmrimethods.org).

Talairach Space vs. MNI Space

In a series of commentaries between researchers (Devlin and Poldrack, 2007; Toga and Thompson, 2007; Tzourio-Mazoyer et al., 2007; Van Essen and Dierker, 2007; and others), many agreed it would be beneficial to the neuroimaging community to reach a consensus for methods of localizing neuroanatomical regions with precision and accuracy. Devlin and Poldrack (2007) argued that the neuroimaging community should abandon the Talairach and Tournoux atlas (1988), and, with one exception, based their reasoning solely on the nature of the anatomical labels published in the 1988 atlas: (1) the single-subject anatomy is not representative of the general population, (2) almost all major software packages use MNI templates, (3) the atlas is based on only a single hemisphere, and (4) the precision of the labeled Brodmann areas is highly misleading. However, while these are valid criticisms as to why Talairach *labels* are not optimal, they do not directly pertain to a recommendation to abandon Talairach *space*. That is, being “Talairach compliant” is not the same as being limited to using the specific anatomical labels delineated in the 1988 Talairach and Tournoux atlas. Furthermore, being Talairach compliant does not prevent the creation of probabilistic, automated naming tools such as the Talairach Daemon or the cytoarchitectonic labels of the SPM Anatomy Toolbox (Eickhoff et al., 2005; 2006; 2007).

Talairach space is defined as the standard brain space with the same dimensions as the published 1988 atlas (x = 136mm, y = 172mm, z = 118mm), in which the y-axis corresponds to the anterior commissure-posterior commissure (AC-PC) line, and the origin is the AC. Any brain and any template can be made to fit this definition, including the MNI templates. For example, in the SPM Anatomy Toolbox, probabilistic cytoarchitectonic maps are corrected by a linear shift such that the origin is the anterior commissure in order to move images from “original MNI space” to “anatomical MNI space” (Eickhoff et al., 2005). MNI templates do not conform to Talairach-compliant criteria; brains normalized to MNI templates are consistently larger than brains normalized to Talairach space, and are even consistently larger than non-normalized individual subject brains by approximately 24% (Lancaster et al., 2007). The frequent assertion that MNI brains are more representative of the general population seems contradicted by their inflated scalar dimensions.

The popularity of the MNI templates results from the fact that they are continuously sampled MRI data sets, which allow use of automated spatial normalization algorithms that cannot be driven by the dimensions or contours derived from the 1988 Talairach atlas. Having a procedure that is intrinsically suitable for automated spatial normalization methods

is important. The Talairach atlas is not amenable to this type of analysis, since no standard group template was distributed with the 1988 publication. It is therefore undeniable that MNI templates are highly desirable, given their utility in automated spatial normalization, as well as the well-developed and validated labels that are representative of the general population (Eickhoff et al., 2005; 2006; 2007). A significant drawback to the use of MNI template is that an anatomical atlas was not concurrently released, which is the *sine qua non* for defining an anatomical space. Only through *post hoc* community efforts has the MNI305 template gradually evolved toward a space with defined structures and probabilistic structural variability.

There is a vast volume of published data in the literature that is Talairach compliant. To abandon this standard undermines the advantages in neuroanatomical standards that we have achieved as a field. In any field, a researcher should have the ability to compare new experimental results to any study that preceded it, such as in quantitative, coordinate-based meta-analyses. Introducing any additional non-Talairach compliant (and non-MNI compliant) templates in the future would further compound this mistake. We therefore recommend that any future templates be distributed as Talairach compliant, or be published and released to the community only with an accompanying space-defining atlas with a validated transform to Talairach compliance.

Conclusions

A quantitative comparison of the Brett transform (i.e., “mni2tal”) and Lancaster transform (i.e., “icbm2tal”) was performed in order to determine the best choice for reducing disparity between Talairach and MNI coordinates in functional neuroimaging results. FMRI data acquired during a standard paired associates task indicated that the Lancaster transform provides a more accurate coordinate conversion than the Brett transform. Activation likelihood estimation (ALE) of published coordinates from the paired associates literature provided additional evidence that the choice of transform substantially affects coordinate-based meta-analytic studies. Based on these results, we recommend that the neuroimaging community adopt the Lancaster transform as a method of reducing the disparity between Talairach and MNI coordinates.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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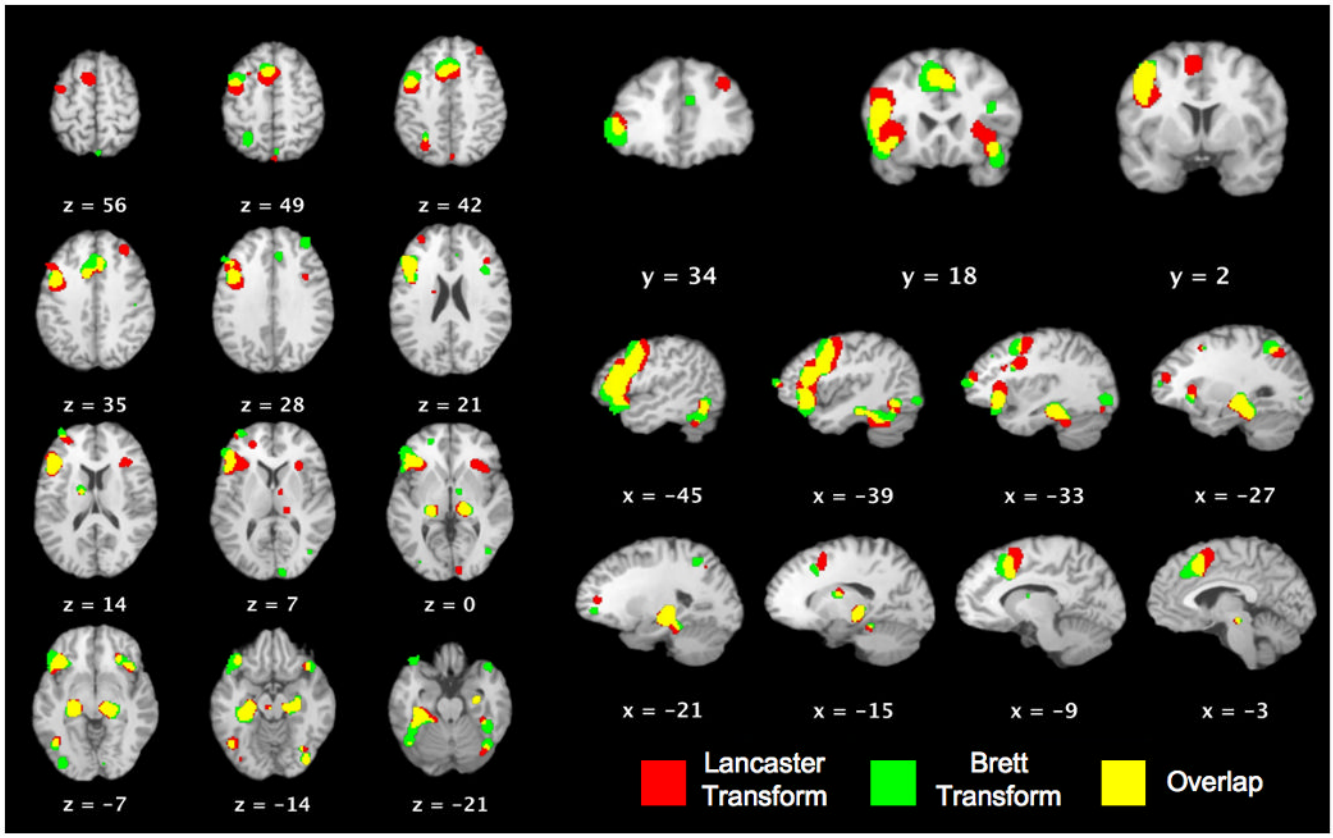

Figure 1. Effect of Transform in ALE Meta-Analysis of Encoding

The ALE meta-analysis for encoding of paired associates was performed using Lancaster (icbm2tal; red) or Brett (mni2tal; green) transforms for spatial renormalization of MNI coordinates. Areas of overlap between the two meta-analyses are seen in yellow. This figure indicates that this choice has a substantial effect on coordinate-based meta-analyses. The Brett transform produced a nose-down correction, while the Lancaster transform produced a nose-up correction. Largest areas of difference occur in the superior and anterior regions of the brain, while areas of agreement are observed in the medial temporal cortices.

Table 1
Spatial Normalization Template and Software Reporting In BrainMap

The BrainMap database is an online archive of published neuroimaging results in the form of stereotactic coordinates (Fox and Lancaster, 2002; Laird et al., 2005a). As of September 2009, BrainMap contained a total of 1822 functional neuroimaging papers, with publication dates ranging from August 1985 to August 2009. The template and software used during spatial normalization is recorded for each paper. A total of 797 papers published coordinates in Talairach space (43.7%) (citing either the 1988 or 1967 atlases). This includes 27 papers that referenced the Human Brain Atlas (Roland et al., 1993), which are arguably not Talairach coordinates. There were 873 papers that published results in which subject brains were normalized relative to MNI space (47.9%), and 152 papers that normalized to MNI space but stated that they used the Brett transform to convert their MNI coordinates to Talairach coordinates (8.3%).

Template - Software	Number of Papers	Total Percent
Total Talairach 1988 **or 1967**	**797**	**43.7**%
Talairach 1988	374	20.4
Talairach 1988 – AFNI	115	6.3
Talairach 1988 – AIR	27	1.5
Talairach 1988 – BRAINS	11	0.6
Talairach 1988 – Brain Voyager	66	3.6
Talairach 1988 – BrainVOX	2	0.1
Talairach 1988 – Human Brain Atlas	27	1.5
Talairach 1988 – LIPSIA	26	1.4
Talairach 1988 – MedX	28	1.5
Talairach 1988 – SPM 4.0	3	0.2
Talairach 1988 – SPM94	5	0.3
Talairach 1988 – SPM95	103	5.7
Talairach 1967:HD6	5	0.3
Talairach 1967:vf25	5	0.3
Total MNI	**873**	**47.9**%
MNI – FSL	38	2.1
MNI – In-House	46	2.5
MNI – SPM5	19	1.0
MNI – SPM2	204	11.3
MNI – SPM96	130	7.1
MNI – SPM97	28	1.5
MNI – SPM98	1	0.1
MNI – SPM99	386	21.3
MNI – Unknown SPM	13	0.7
MNI – Other Software	8	0.3
Total Brett Transform	**152**	**8.3**%
Brett Transform – SPM5	3	0.2

Template - Software	Number of Papers	Total Percent
Brett Transform – SPM2	56	3.0
Brett Transform – SPM96	5	0.3
Brett Transform – SPM97	1	0.1
Brett Transform – SPM99	85	4.6
Brett Transform – Other Software	2	0.1
Total	**1822**	**100**%

Table 2

Talairach, MNI, and Converted MNI Coordinates for Recall > Baseline

Two sets of coordinates were obtained for a sample contrast (Recall > Baseline), based on normalization to (a) Talairach space (9 clusters) or (b) MNI space (10 clusters). Small differences in cluster centers of mass and extents were observed between the images. Coordinates were closely examined to find matching pairs (as seen on the same line). 7 matching coordinates were observed. The Euclidean distances, d, between the MNI and Talairach pairs of coordinates were computed and averaged to obtain a mean value of 6.743 mm. MNI coordinates obtained for the Recall > Baseline contrast were converted to Talairach coordinates using (c) the Brett transform (mni2tal) and (d) the Lancaster transform (icbm2tal). Euclidean distances were also computed and averaged from the converted coordinates to the Talairach coordinates.

	(a) Talairach Coordinates				(b) MNI Coordinates				
	x	y	z	Z	x	y	z	Z	d
	-4	-90	-6	9.42	-4	-92	-8	9.08	2.828
	-14	-16	6	7.56	-12	-14	6	8.09	2.828
	-4	14	40	7.06	2	20	44	8.17	9.381
	42	6	24	6.68	44	10	24	6.46	4.472
	30	18	0	6.49	38	20	-8	6.66	11.489
	-40	50	2	4.71	-42	56	-2	4.87	7.483
	40	-32	42	4.30	46	-34	48	4.43	8.718
Average Distance Between Talairach and MNI Clusters = 6.743 mm									
Tal Only	10	-4	0	4.66					
	6	-88	32	4.60					
MNI Only					26	-94	-4	7.29	
					-42	28	14	6.44	
					48	40	22	5.52	

	(c) Converted Using Brett Transform				(d) Converted Using Lancaster Transform			
	X	Y	Z	d	X	Y	Z	d
	-3.96	-89.52	-2.85	3.187	-5.15	-87.73	-9.72	4.507
	-11.88	-13.27	6.16	3.460	-12.49	-14.54	7.67	2.683
	1.98	21.51	39.51	9.613	0.78	15.37	44.08	6.432
	43.56	10.85	21.59	5.636	40.55	6.70	25.66	2.313
	37.62	18.99	-7.55	10.773	34.98	18.08	-2.58	5.609

-41.58	54.16	-4.03	7.494		-40.62	52.52	4.62	3.688
45.54	-30.61	45.67	6.789		42.23	-36.42	44.58	5.583
Average Distance = 6.707 mm					**Average Distance = 4.402 mm**			

Table 3
Average Distances from Talairach Coordinates to Converted MNI Coordinates

Euclidean distances from the converted coordinates to the Talairach coordinates were computed and averaged for all four contrasts. Overall, use of the Lancaster transform (icbm2tal) best reduced the disparity between Talairach and MNI coordinates.

	No Transform (MNI Coordinates)	Brett Transform (mni2tal)	Lancaster Transform (icbm2tal)
Learn > Distract	7.324	9.598	5.465
Recall > Distract	6.743	6.707	4.402
Learn > Recall	8.599	8.777	8.134
Recall > Learn	8.461	8.723	7.133
Average	**7.782 mm**	**8.451 mm**	**6.284 mm**

Table 4

Regions of Convergence Observed for Encoding and Recall Meta-Analyses

ALE meta-analyses were performed on the published coordinates for (a) encoding and (b) recall of paired associates, using either the Lancaster or Brett transform. Euclidean distances, d, between matched coordinates were computed, yielding an average of 7.5 mm distance between pairs. Some clusters observed in the Lancaster transform meta-analysis were split into multiple clusters in the Brett meta-analysis, and vice versa. Other clusters were observed only in the Brett results, or only in the Lancaster results. Maximum ALE scores for each cluster are also provided.

(a) Encoding

Lancaster Transform				Brett Transform				
ALE	**x**	**y**	**z**	**ALE**	**x**	**y**	**z**	**d**
0.0168	-40	-2	46	0.0163	-42	6	42	9.165
0.0138	-40	2	30	0.0118	-42	8	26	7.483
0.0136	-42	20	24	0.0161	-42	24	18	7.211
0.0121	-42	26	8	0.0127	-46	32	0	10.770
0.0131	-22	-26	-8	0.0133	-22	-26	-8	0.000
0.0125	-30	-34	-18	0.0130	-30	-36	-18	2.000
0.0097	-38	-44	-28	0.0096	-40	-48	-24	6.000
0.0081	-42	-56	-30	0.0099	-44	-62	-22	10.198
0.0068	-16	-38	-20	0.0064	-16	-42	-18	4.472
0.0158	-6	8	50	0.0138	-6	18	42	12.806
0.0126	2	14	44	0.0118	6	22	38	10.770
0.0078	6	24	34	0.0078	8	32	26	11.489
0.0115	16	-28	-2	0.0113	20	-28	-4	4.472
0.0081	28	-18	-18	0.0086	30	-16	-18	2.828
0.0094	38	18	-10	0.0104	42	18	-16	7.211
0.0097	-42	-64	-14	0.0083	-42	-66	-8	6.325
0.0092	38	-42	-28	0.0105	42	-46	-24	6.928
0.0100	32	38	38	0.0099	36	46	28	13.416
0.0073	40	26	18	0.0079	40	14	22	12.649
0.0079	-30	48	18	0.0080	-34	54	12	9.381
0.0091	-26	-66	42	0.0110	-26	-58	48	10.000
0.0066	-14	-8	14	0.0077	-14	-6	14	2.000
				Average Distance = 7.617 mm				

0.0117	-38	24	-8	Split in Brett	0.0115	-40	24	-14
					0.0107	-36	24	-4
0.0079	38	-82	-14	Split in Brett	0.0100	40	-64	-24
					0.0080	36	-82	-14
0.0083	28	22	2	Split in Lancaster	0.0092	28	26	-8
0.0068	26	30	-8					
				Brett Only	0.0087	-34	-86	-6
					0.0073	10	-94	6

(b) Recall

Lancaster Transform				**Brett Transform**				
ALE	**x**	y	z	**ALE**	**x**	**y**	**z**	**d**
0.0112	-46	4	38	0.0084	-44	0	42	6.000
0.0091	-48	26	26	0.0088	-46	18	20	10.198
0.0087	-28	24	2	0.0084	-30	26	-6	8.485
0.0084	-34	-2	50	0.0081	-34	6	48	8.246
0.0139	-4	4	54	0.0202	-4	12	52	8.246
0.0120	4	34	22	0.0110	4	36	22	2.000
0.0115	-4	24	40	0.0114	-2	34	32	12.961
0.0147	16	-74	28	0.0131	18	-72	32	4.899
0.0086	-34	-72	24	0.0091	-34	-70	30	6.325
0.0184	34	20	-4	0.0149	38	22	-10	7.483
0.0158	18	48	6	0.0171	20	52	-4	10.954
0.0103	-2	-50	10	0.0099	0	-48	14	4.899
0.0081	0	-52	-8	0.0082	2	-52	-4	4.472
0.0098	-20	42	10	0.0084	-22	48	-2	13.565
0.0094	4	-24	-12	0.0092	4	-24	-12	0.000
0.0066	4	-14	0	0.0064	6	-14	0	2.000
0.0077	32	38	38	0.0075	36	48	28	14.697
								Average Distance = 7.378 mm

0.0103	-44	22	10	Split in Brett	0.0093	-50	20	0
					0.0073	-36	14	8
0.0090	-50	22	26	Split in Brett	0.0083	-50	34	18
					0.0080	-50	14	32
0.0078	-44	20	-6	Split in Brett	0.0092	-46	26	2
					0.0075	-46	20	-12
0.0208	-4	-78	36	Split in Brett	0.0175	0	-74	46
					0.0108	-8	-76	30
0.0113	-34	-54	40	Split in Brett	0.0091	-34	-50	44
					0.0077	-24	-66	38
0.0071	-10	42	2	Lancaster Only				